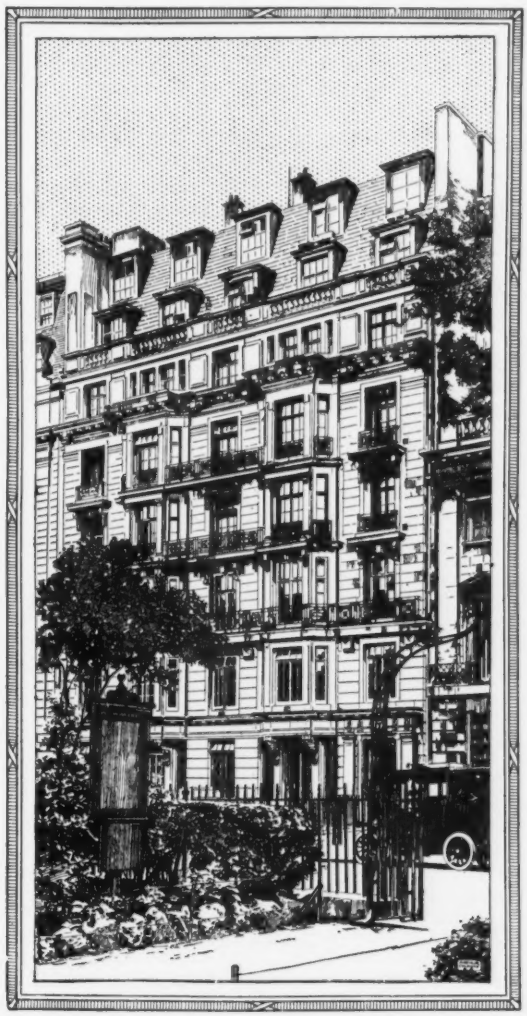
The ENGLISH ELECTRIC JOURNAL



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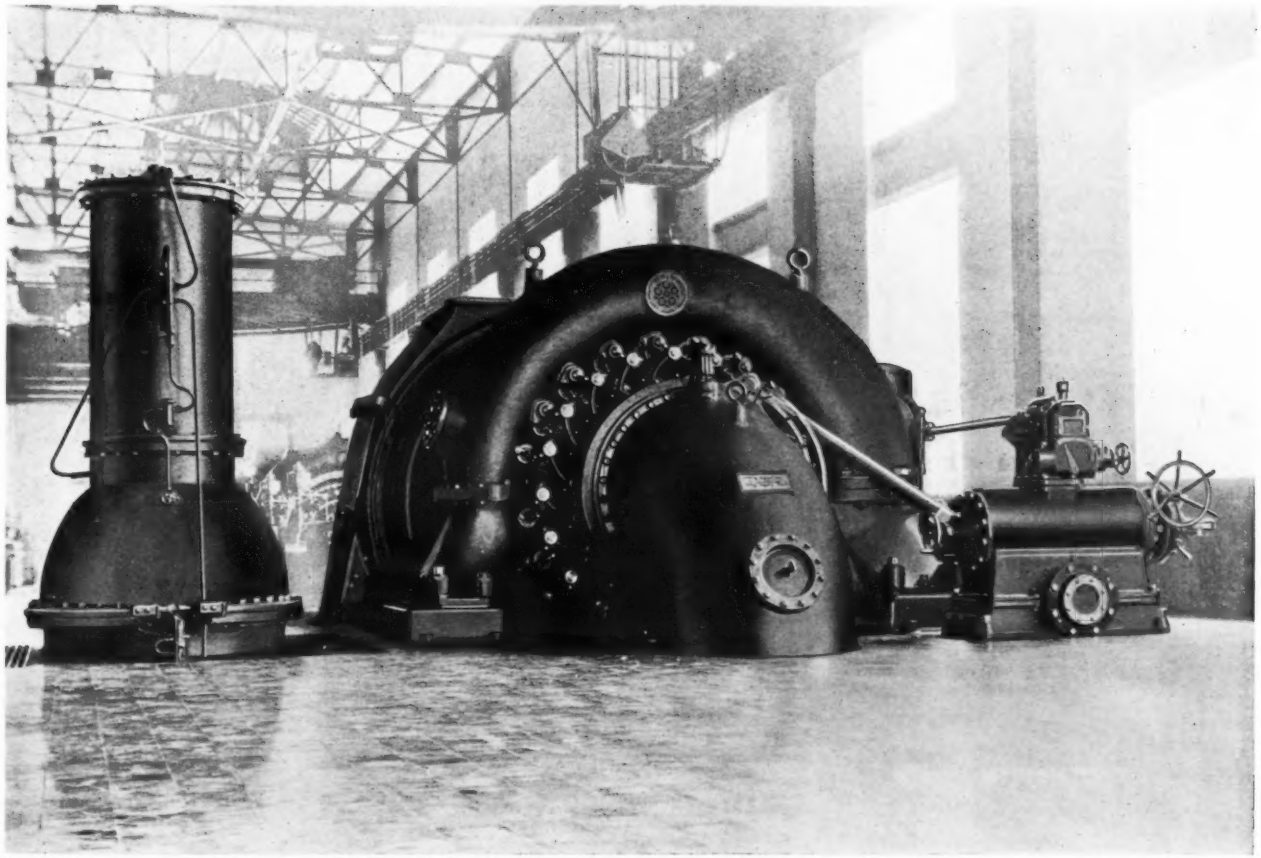

25,000 H P. Water Turbine and Alternator in the Sorocaba Power Station of the Sao Paulo Electric Company, Limited.

The English Electric Journal

Vol III No. 5 JULY, 1926 One Shilling

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C.2.

EDITORIAL.

In a previous issue of this Journal we gave a description of a 15,000 H.P. water turbine of the Impulse type. This machine has now been in satisfactory operation in India for many months, and a special feature has been the close regulation that the machine effects when subject to changes of load. The regulation of the whole load of the station, which contains several turbines of other makes, is controlled by the new machine.

In this issue we describe another large hydraulic turbine that was manufactured in our Rugby Works, and has likewise been in operation on the site for some considerable time. This turbine has an output of 25,000 H.P., and is of the Reaction type. In order to use existing foundations, which had been prepared for a machine of smaller output, a special design had to be evolved and the high speed of 600 R.P.M. adopted. The generator is also of our manufacture, and the combined plant has been subjected to exhaustive tests on site. The efficiency has been proved to be considerably above the guaranteed figures, and the generator has withstood a very exacting short-circuit test without the slightest damage resulting. The regulation

is exceedingly close, and as in the case of the Impulse machine just referred to, our plant takes over the regulation control of the whole station. Every detail of the governing gear, as indeed the whole plant, has been designed and manufactured by us.

We also give a description of the induction regulators manufactured by the Company. These regulators provide the simplest and most convenient means for controlling the voltage of supply on A.C. feeders, and they are also of great service in interlinking schemes to adjust the distribution of energy between the Power Stations. The regulators can be either hand-controlled, or operated automatically through the agency of relays and a small motor-driven mechanism. The Company also manufactures low-voltage induction regulators of the Air-Cooled type for the voltage control of rotary converters.

In the majority of cases where considerable power has to be dealt with, induction regulators provide the best method of control. The regulation effected is smooth and continuous, and no switches are required in the circuits to be controlled.

In another article a description is given of air-break switchgear for some outdoor substations that the Company has recently supplied. The complete equipments, consisting of transformers, induction regulators, and switchgear have been manufactured by the Company. Transformers and switchgear of the outdoor type are in general use abroad, and the Company supplies designs to meet all the requirements of this class of work.

We conclude this issue with short descriptions of the motor equipment supplied by the Company for the operation of two special plants: one, the pumping plant at the Southampton Docks of the Southern Railway; and the other, the purification works of the West Kent Sewerage Board. While the electric machinery is of standard types, the descriptions and illustrations show how the special requirements of each case have been met. Every industry has its own special conditions, which have to be carefully studied if the electric drive is to be successfully applied, and the Company has a staff of Engineers who specialise in this class of work, and determine in each case the most satisfactory arrangements to be adopted. We hope to describe further installations in future issues of the Journal.

A 25,000-H.P. Water Turbine and Alternator.

FIG. 1. GENERAL VIEW OF THE SOROCABA POWER STATION, BRAZIL.

Among the many branches of the engineering industry in which The English Electric Company are actively engaged, one of the most important is the manufacture of water turbines and electric generators for operation in hydro-electric plants.

The Company's experience on the electrical side is well known, and extends back to the earliest days of heavy electrical engineering, but it is only in recent years that they have entered the field of water turbine manufacture. During these years, however, rapid progress has been made, and at the present time the Company have in successful operation in different parts of the world water turbines of very large capacity of both the reaction and the impulse types.

At the outset the Company had at their disposal works and plant capable of dealing with very large units, and on the design side they secured the services of the most skilled and experienced technical advisers. Further, the Company were in a favourable position to handle this class of business, as they had considerable experience in dealing with large comprehensive contracts.

By the courtesy of the Sao Paulo Electric Co. Ltd., it is now possible to give a description of an "English Electric" 25,000 H.P. turbine and generator which has for some considerable time been running successfully in the Sorocaba Power Station. This Power Station is situated on the river bearing the same name, the position being 60 miles west of Sao Paulo, Brazil. A general view of the Power House as seen from the pipe line side is shown in Fig. 1, the pipe line itself being seen in Fig. 2.

The load on the station is dealt with by three 15,000 H.P. units, previously installed, and the 25,000 H.P. set now referred to.

One of the purposes for which the new set was

FIG. 2.
GENERAL VIEW OF THE PIPE LINE AND TRANSMISSION LINE.

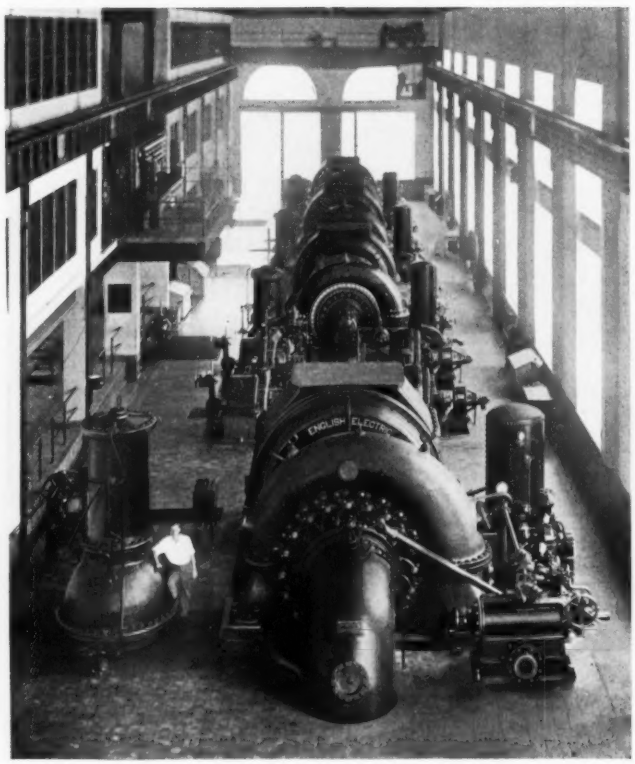


FIG. 3.
INTERIOR OF SOROCABA POWER STATION SHOWING 25,000 H.P. "ENGLISH ELECTRIC" SET IN THE FOREGROUND.

installed was to take up the change in load for the whole Power Station, while the old units were left working practically continuously at their normal load. It will, therefore, be realised that the new unit had to have a very precise and close speed regulation. This close speed regulation had to be effected with a minimum of disturbance on the transmission line and in the penstock, which necessitated a series of refinements in the design of the automatic governing gear.

It is also to be noted that the design of the turbine required special consideration owing to the fact that it had to be erected on foundations already prepared for a unit of the smaller size previously installed in the station, and the necessity of getting the 25,000 H.P. unit into the space available, and of working with a high efficiency, led to the adoption of an unusually high speed for this type of machine. Further, on account of the levels of the existing foundations, the unit had to be placed in an unusually high position above the tail race water. All these special requirements render this unit interesting, not only as an example of large up-to-date machinery, but also as marking distinct progress in the design of high pressure hydraulic plants. The whole of the plant is British, all parts, including the complete governing mechanism, having been made in The English Electric Company's Works.

The turbine is of the reaction type and operates under a head of 670 ft., with a rated output of 25,000 H.P. at 600 R.P.M. The maximum discharge of water is 400 cubic ft. per second, and the specific speed is, therefore, 29·2 British units, which is a record for the head under which the turbine has to work.

The general arrangement of the set is shown by the drawing reproduced in Plate I, while Fig. 3 and the Frontispiece show the plant as seen from the turbine end. Fig. 3 shows the interior of the Power House with the new set in the foreground, and Fig. 4 is a view of the set taken from the alternator end.

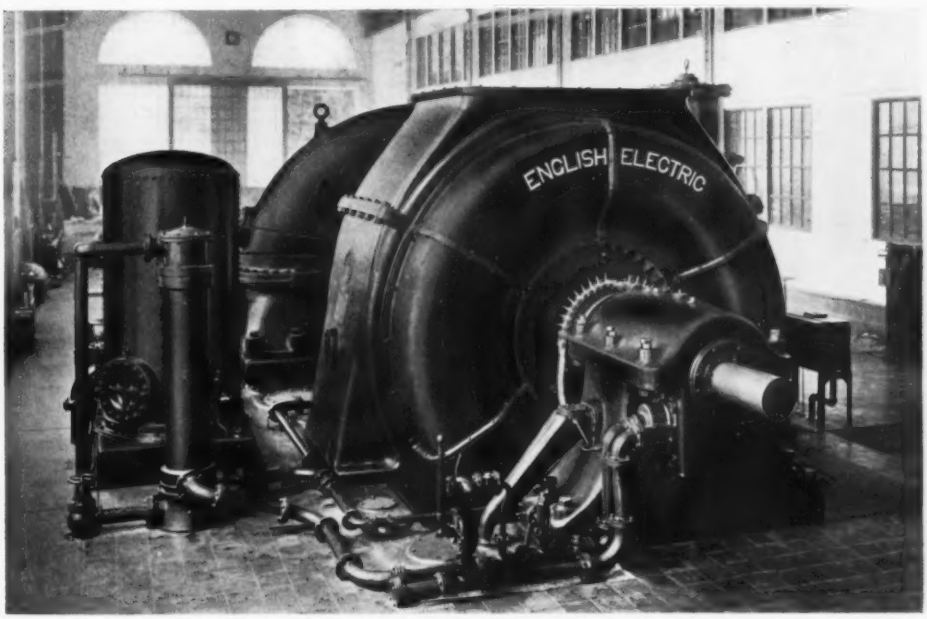


FIG. 4. VIEW OF THE 25,000 H.P. SET FROM THE ALTERNATOR END.

As can be seen from these illustrations, the unit is of the horizontal shaft type, with two bearings, spiral casing, and a single runner overhung on the alternator shaft.

A turbine of this capacity and speed, and designed to work under so high a head of water, presents many interesting points in its construction. The centring of the runner is, for instance, a specially important consideration as, on account of the high head and relatively small quantity of water, the clearance between the runner and its surrounding casing must be very small indeed to avoid undue water losses, which would be detrimental to the efficiency of the set. This makes it essential that the runner should not move in a longitudinal direction relative to the casing, and apart from any purely mechanical movement which might affect the clearance, the design has to be such that the expansion due to the normal rise in temperature of the alternator when under load shall not cause a diminution in the normal clearance.

These requirements have been met by carrying the generator and turbine casing on a combination bedplate which, in the part beyond the generator, is formed with a forked extension on which the spiral casing is bolted, and in addition to this the turbine casing has been stayed to the main inboard bearing by two heavy bolts. The inboard bearing forms the thrust bearing of the machine, so that any expansion of the generator shaft takes place in the direction of the outboard bearing and does not affect the clearance of the runner.

This design definitely fixes the centring of the runner relatively to its surrounding parts and, at the same time, secures the rigidity of the casing and of all stationary parts. The bedplate and bearings are shown in Fig. 5, which shows the rotor of the alternator being erected at the Company's works for the overspeed test.

The clearance spaces between the runner and the casing lie between forged steel rings, the faces of which are shaped in section like a comb, which are secured to the runner and to the casing respectively. The rings attached to the casing engage with those attached to the runner and thus form labyrinth passages. The position of the rings is adjustable, and the

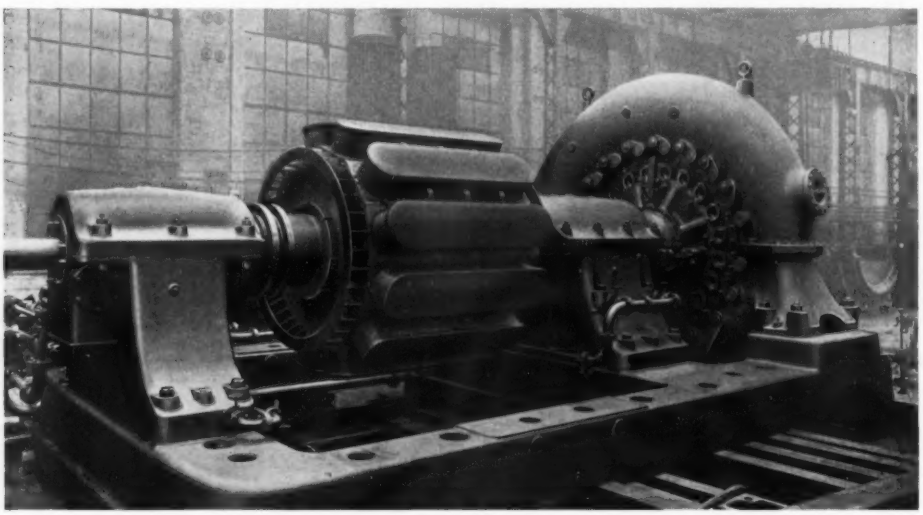


FIG. 5. ALTERNATOR ROTOR ERECTED AT PRESTON WORKS FOR OVERSPEED TEST.

FIG. 6. TURBINE RUNNER FROM DISCHARGE SIDE.

original clearances can be maintained even after the rings are slightly worn. The rings in question can be seen in Figs. 6 and 7, which are views taken from the actual runner, and also in Fig. 8 showing the runner in the casing.

The spiral casing is of cast steel and is designed without stay vanes, these being replaced by a series of strong chrome-nickel steel rods, screwed at both ends, which hold the two sides of the spiral against the pressure of the water. This construction presents considerable advantage as compared with a cast vane construction, which is subject to dangerous cooling stresses and minute cracks in the course of manufacture. Further, to obtain the maximum efficiency the casing has the form of a logarithmic spiral, which gives a perfect intake vortex and ensures that the water all round the guide apparatus has the same entrance velocity. All disturbing eddies are, thereby, avoided.

The guide apparatus consists of twenty swivel vanes, which can be seen in Fig. 8, connected to the regulating ring by levers and breaking links. The vanes are of cast steel, and each is cast in one piece with its trunnions. Particular care has been devoted to the design of these parts in view of the high velocities reached by the water in this particular region. The breaking links are of cast iron and are easily renewable; they are intentionally designed to form the weakest part of the regulating apparatus, so that in the event of any foreign body becoming jammed between the guide vanes the links break and thus provide full security against the possibility of further damage to the plant.

The runner is bolted to a flange at the end of the generator shaft, the torque being transmitted by two keys. As a precaution against corrosion and pitting it is cast in Turbadium bronze, an alloy which has proved itself eminently suitable for this purpose and which, in addition,

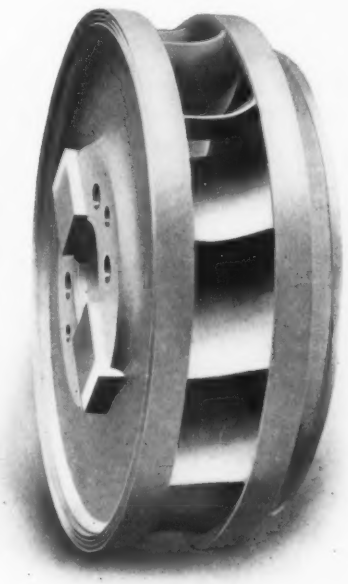


FIG. 7. TURBINE RUNNER FROM DRIVING SIDE.

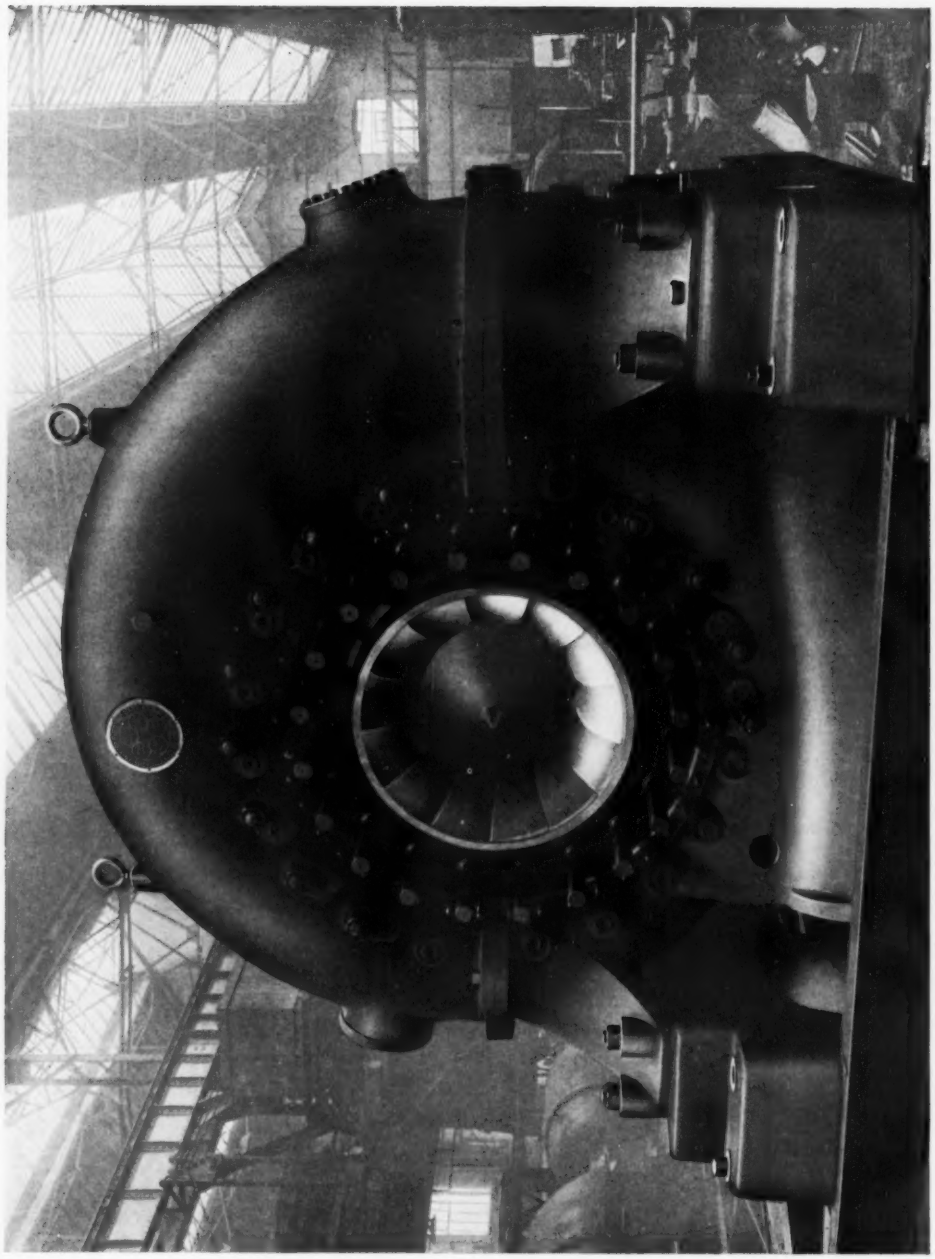
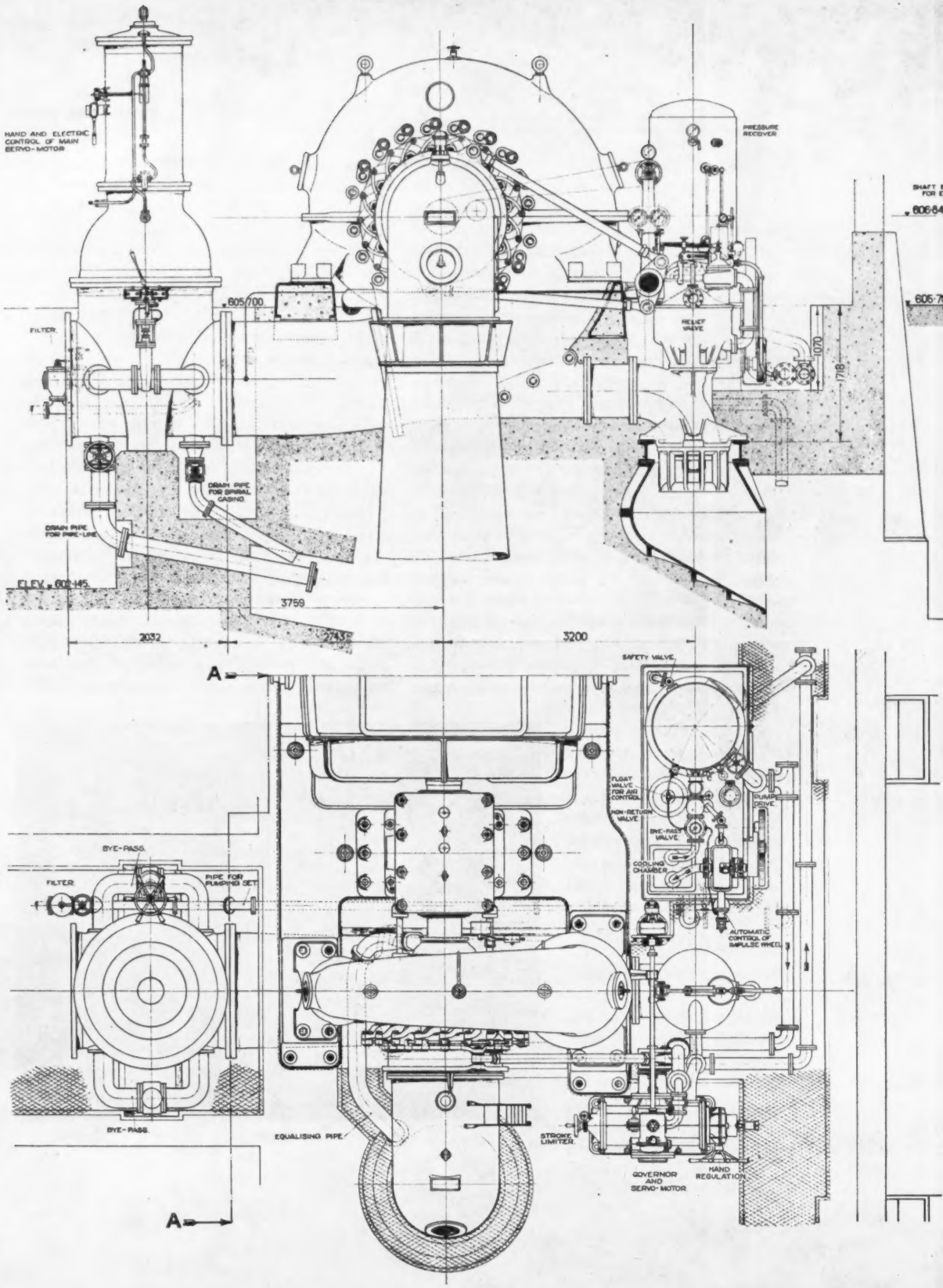
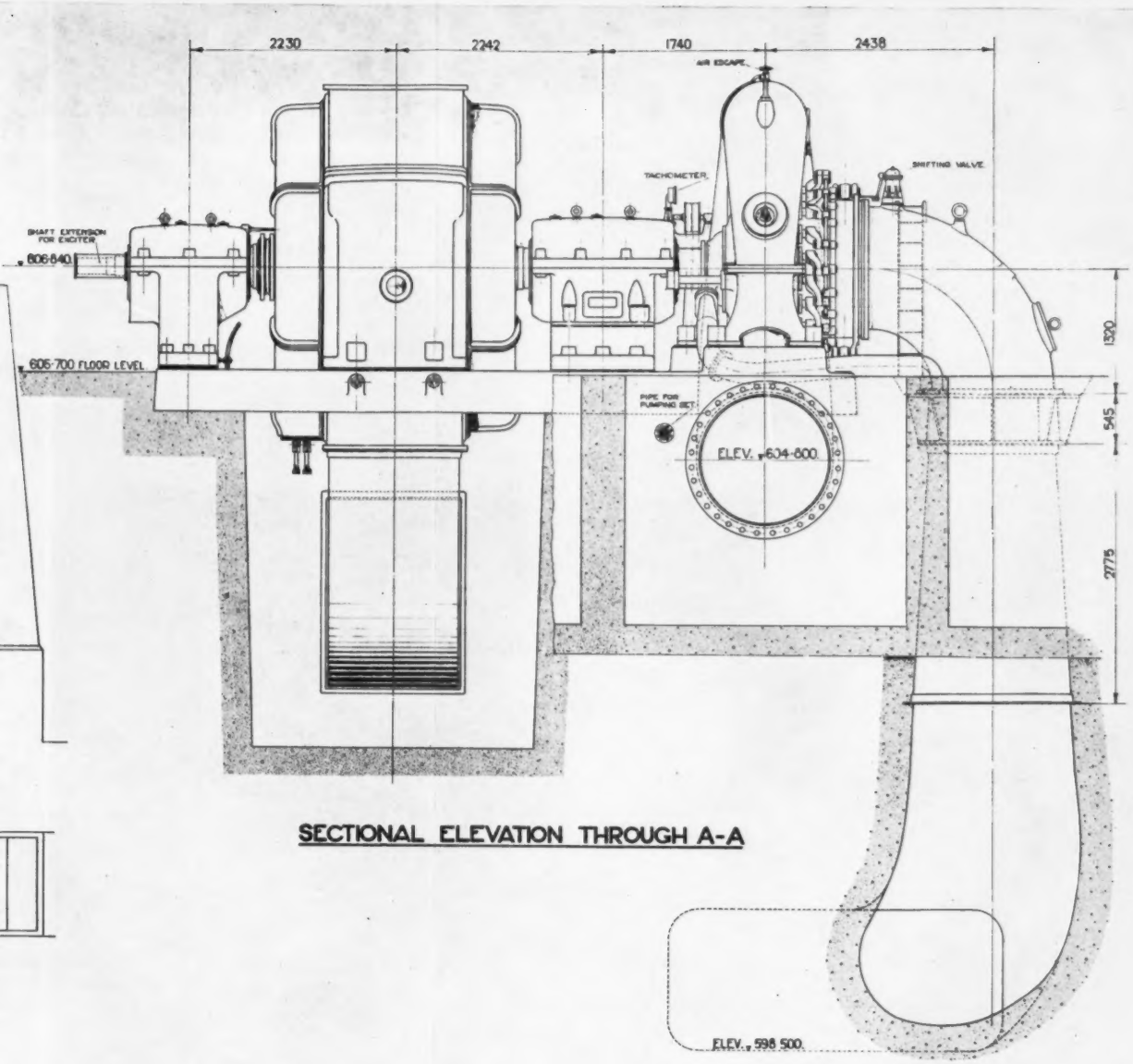


FIG. 8. VIEW DURING ERECTION AT PRESTON WORKS, SHOWING CASING, GUIDE VANES AND RUNNER.


HAND AND ELECTRIC CONTROL OF MAIN SERVO-MOTOR
PRESSURE RECEIVER
FILTER
DRAIN PIPE FOR SPIRAL CASING
DRAIN PIPE FOR PIPE-LINE
ELEV. + 602·145
3759
2032
2743
3200
1070
1718
SAFETY VALVE
FLOAT VALVE FOR AIR CONTROL
NON-RETURN VALVE
BYE-PASS VALVE
COOLING CHAMBER
PUMP DRIVE
AUTOMATIC CONTROL OF IMPULSE WHEEL
BYE-PASS
FILTER
PIPE FOR PUMPING SET
BYE-PASS
EQUALISING PIPE
STROKE LIMITER
GOVERNOR AND SERVO-MOTOR
HAND REGULATION
A
A



SECTIONAL ELEVATION THROUGH A-A

"ENGLISH ELECTRIC"
25,000 H.P. WATER TURBINE & ALTERNATOR
FOR
SOROCABA POWER STATION, BRAZIL.

possesses great strength. Though the output is a large one, nevertheless the high pressure and the high speed under which this reaction type runner operates has made it possible to keep its dimensions remarkable small, and it will be of interest to mention that the velocity of the water, relatively to the vanes, reaches 130 ft. per second.

After leaving the runner the water flows through a trumpet formed pipe section, which is lined with Turbadium bronze to prevent corrosion, and thence through a 90 degrees bend to the suction tube and tail race. The upper part of the suction tube is lined with sheet steel while the lower part is of concrete.

An automatic air snifting valve is fitted to the 90 degrees bend in order to avoid undue suction in the case of the sudden closing of the gate apparatus. In this event, the flow of the water through the guide apparatus is quickly checked, but not the flow through the draft tube, and as a result a sudden drop of pressure occurs in the draft tube, which, in the absence of an air snifting valve, may be followed by a heavy concussion. A drop of pressure of this nature is detrimental in that corrosion of the surrounding parts is likely to occur, and the ensuing concussion is a possible source of danger to the plant. The air snifting valve allows air to enter at the top of the draft tube, the quantity of air so admitted being such that excessive vacuum is rendered impossible, and no subsequent return of the water column against the runner wheel, which is the cause of the concussion, can occur.

The snifting valve is controlled by the governor, but is also capable of opening automatically if, for any reason, there is an undue drop in pressure independent from that caused by governor regulation. Further, a too quick closing of the valve is prevented by the fitting of a suitable dashpot.

The speed of the set is controlled by an automatic oil pressure governor of the " English Electric" standard type (see Figs. 9 and 10) which consists essentially of an enclosed dust-proof actuator and a servo-motor. The design of the actuator is such that the compensation effected by the return motion gear on the distributing valve is of a temporary nature, and hence the speed can be kept constant for all loads and there is no necessity for a permanent speed variation. Since, however, a certain amount of permanent speed variation is usually required when generating sets run in parallel, a device is provided which allows of permanent speed adjustment up to 5% between full load and no-load.

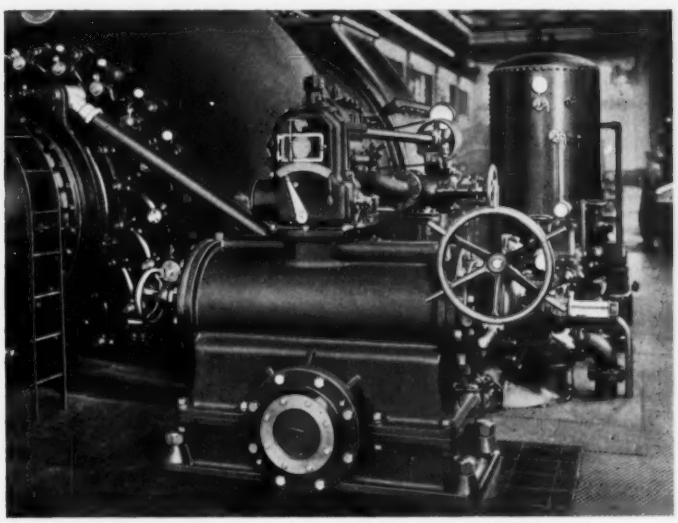


FIG. 9. THE GOVERNOR GEAR.

In addition to the main pendulum, which is designed to give great sensitiveness and so to ensure close regulation, there is an auxiliary pendulum which acts only when the speed rises or drops 30% above or below normal. This pendulum controls an emergency device which

shuts down the set on any abnormal occurrence, such as runaway or breakage of belts. The oil pressure tank that operates in conjunction with the governing mechanism is fed by an oil pump driven by a small impulse turbine. In order to save energy and to prevent unnecessary wear, the pumping set is provided with an automatic controlling device, so arranged that the small turbine, though it is kept running permanently, is loaded only during the time necessary to replenish the pressure receiver.

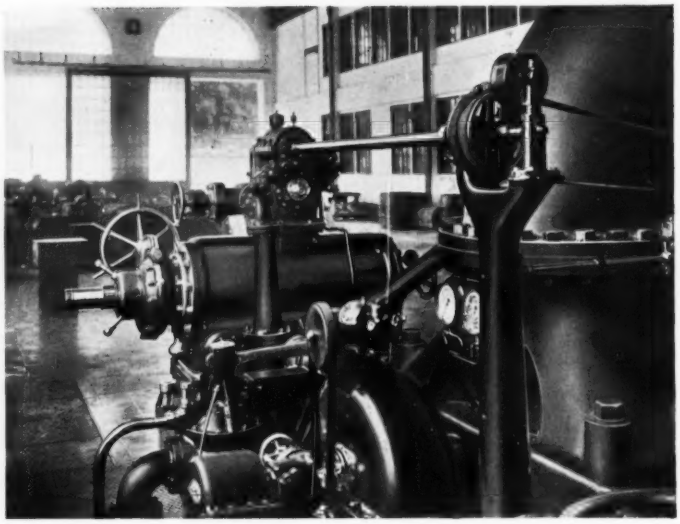


FIG. 10. GOVERNOR GEAR SHOWING TURBINE DRIVING OIL PUMP.

A very close speed regulation is required, and in the case of a sudden drop in load from 25,000 H.P. to zero, the turbine guide vanes are closed in $1\frac{1}{2}$ seconds. To meet these exacting conditions the governor is designed to be of the double-acting type, that is to say, simultaneously with the closing of the guide apparatus of the turbine a relief or bye-pass valve is opened to a corresponding extent, and the water which is no longer required by the turbine is bye-passed down to the tail race. The control of the bye-pass relief valve is entirely automatic, through the agency of the governor actuator and servo-motor, and it closes under the influence of an independent dashpot. The rate of closing is adjusted so as to reduce the waste of water to a minimum and at the same time to keep the pressure rise in the pipe line within predetermined safe limits. An interesting view is shown in Fig. 13 of the tail race at the moment when the output of the set was reduced from full load to zero.

The results of the official tests on the turbine are shown in Figs. 11 and 12. Water measurements taken in connection with the efficiency test were made by the salt velocity method, the accuracy of which was further checked against volumetric measurements, which showed that the salt velocity method was correct within an average of ·3 of 1%.

It will be seen from the curves in Fig. 11 that the efficiency is as high as 88·7%, and there is no doubt that if it had not been necessary to arrange the turbine and draft tube to suit existing foundations prepared for a smaller set, the efficiency would have exceeded 90%.

The tachograms of Fig. 12, show the rapid action of the governor and the remarkable steadiness of the regulation.

The alternator is of interest in many respects. The design, as a whole, was governed by the conditions of transport to the site, which made it necessary that no part should exceed in weight the small figure of seven tons when packed for shipment. Further, the high speed and very high overspeed test for the large output required called for the adoption of many special features in the mechanical construction.

The machine has a full-load output of 20,500 KVA., three-phase, 60 cycles per second, at a

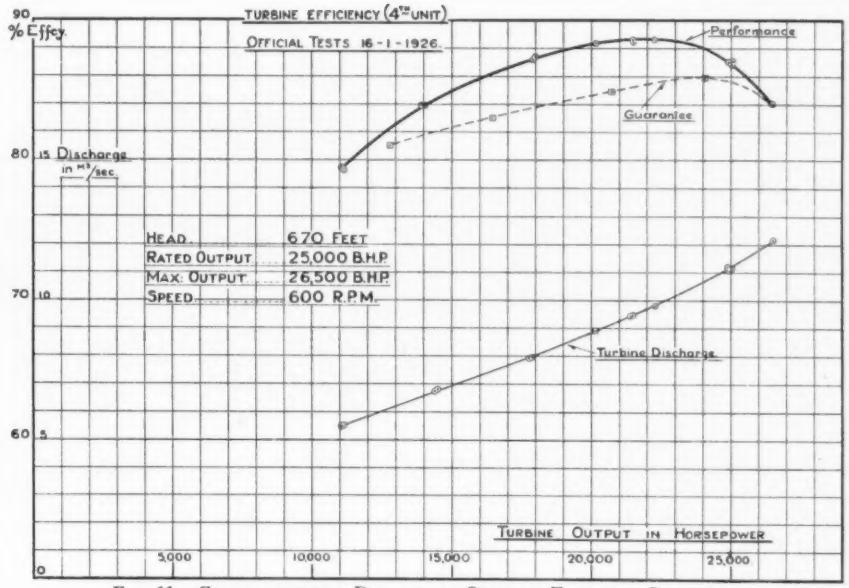


FIG. 11. CURVES SHOWING RESULTS OF OFFICIAL TRIALS AT SOROCABA.

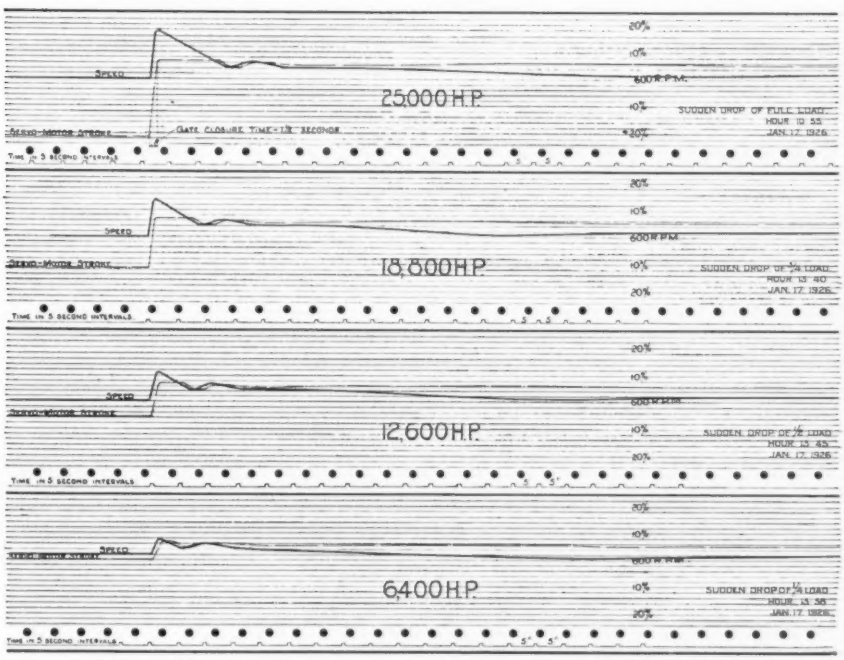


FIG. 12. TACHOGRAMS ILLUSTRATING THE RAPID AND STEADY GOVERNING.

FIG. 13. VIEW OF TAIL RACE AT THE MOMENT FULL LOAD WAS THROWN OFF.

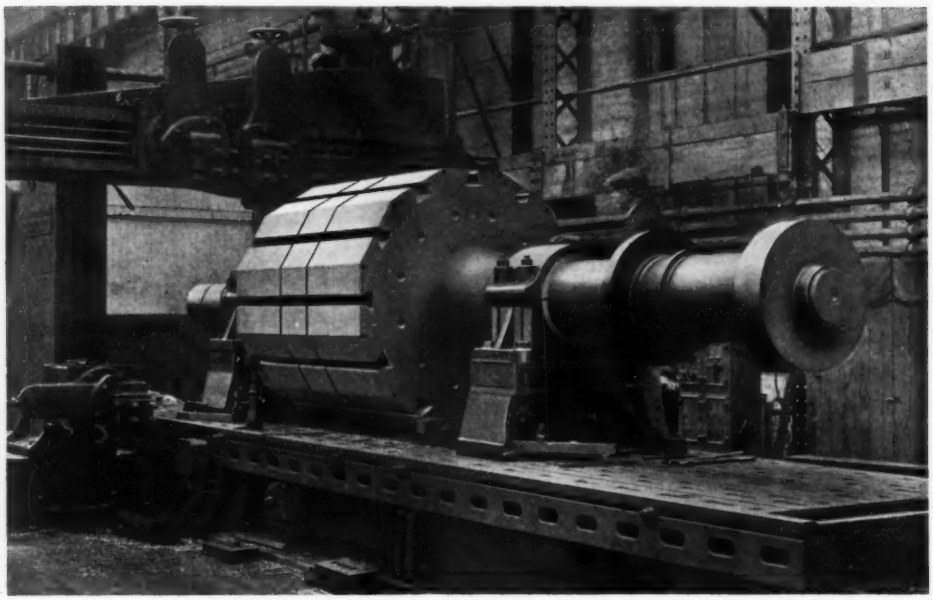


FIG. 14. MACHINING THE ROTOR BODY OF THE ALTERNATOR.

power factor of 0·88 and a pressure of 6,600 volts, when running at 600 R.P.M.

The rotor is of the salient pole type, being designed to withstand an overspeed test of 1,140 R.P.M., under which conditions the peripheral velocity of the pole tips is nearly five miles per minute, and is thus comparable with the speed of cylindrical type rotors coupled to steam turbines. The type of rotor finally decided upon is illustrated in Figs. 5 and 14. The rotor body is made in five parts, each being formed of a packet of many half-inch plates of high-grade rolled steel bolted between heavy rolled steel end clamping plates. This class of material is the most reliable obtainable for such conditions, possessing as it does high ultimate strength and elasticity, and when running at the specified overspeed the rotor body is nowhere subject to stresses exceeding 50% of the elastic limit.

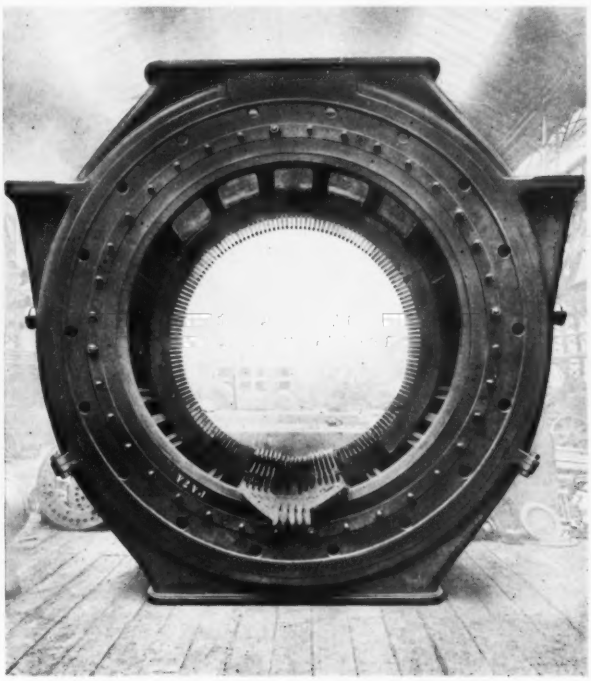


FIG. 15. THE STATOR FRAME ERECTED AT WORKS.

In order to meet transport conditions the rotor had to be completely dismantled after successfully passing the overspeed test in the works, and a novel method, which has since become standard practice, was devised for obtaining the heavy interference fit necessary to keep the body tight on the shaft when running at overspeed. Each packet in turn was heated at the periphery by induced currents from an insulated coil of copper strip passed round the circumference, and the bore was thus expanded until the packet could be gently pushed on or off its proper seating. The power required was inconsiderable, and the operation being under complete control ensured accurate assembly. The process was successfully repeated on site.

The poles are of high grade steel laminations secured by dovetails to the rotor body. One dovetail is used per pole, and accurately fitted into its slot without keys. Owing to the flywheel effect specified, it was necessary to make the rotor longer than the stator, and heavy manganese bronze pole end pieces were used for this purpose. The field winding is of copper strip wound on edge on a metal spool, with mica insulation between turns and to earth. The sliprings are of nickel steel insulated with mica, and the brushgear is of very robust design on account of the large exciting current (750 amps.) which is required, owing to the low voltage of the existing central excitation system.

The shaft is of forged steel and is designed to carry the overhung turbine runner with very conservative stresses, and the critical speed is well above the runaway speed.

In order to keep the stator within shipping limits it was necessary to cast the frame in three sections and to build the

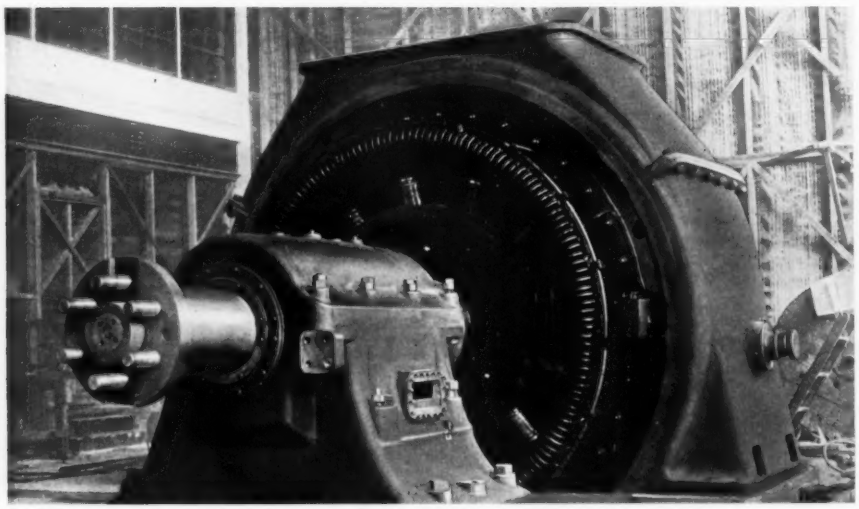


FIG. 16. THE ALTERNATOR IN COURSE OF ERECTION AT SOROCABA.

core and fit the windings on site. The winding is of the two-layer or basket type, mica - insulated throughout and securely supported against short-circuit stresses. Fig. 15 shows the stator frame erected at the Preston Works of the Company, while Fig. 16 shows the completed stator after assembly on site.

The machine is self-ventilated by fans on the rotor, and the heated air is exhausted to a duct in the foundations. In spite of the high speed and the open air inlet from the station, the machine has proved to be very quiet in operation.

The pedestal bearings are of the spherically-seated type with both oil ring and flood lubrication. The outboard pedestal contains a gear driven oil pump which circulates the oil through a water-cooler to both bearings. The thrust bearing, which is at the turbine end of the machine is capable of taking a load of 18 tons in either direction. This bearing is of the Michell type, receiving oil from the main pump, and it has successfully fulfilled its purpose without adjustment.

The machine was submitted to exhaustive tests on site, which included a short-circuit test of unusual severity. The field volts and amperes were adjusted for the full load of 18,000 KW. at 7,200 volts, and the main switch was then closed on a solid short circuit, which was maintained for ten seconds. At the instant of closing the circuit breaker a slight flash from the field collector brushes was noticed, but there was no other evidence of any unusual condition, and the sound of the running machine remained perfectly normal. On examination after shutting down it was found that the anchor rings which hold the windings had remained securely in their places, and had not even cracked the exterior coat of varnish applied to them at the points where they are attached to the brackets on the frame. In no case could any movement be detected which would in any way cause deterioration or injury to the coil insulation.

The behaviour of the alternator on short circuit and the general performance of the entire unit under test indicated that the plant is fully capable of carrying out the duties for which it was designed. These indications have been fully realised since the unit has been in commercial service, and a point of special interest has been the closeness and accuracy of the governing. The machine regulates not only its own output but also the whole output of the Power Station.

Outdoor Air-Break E.H.T. Switchgear at Preston and Blackburn.

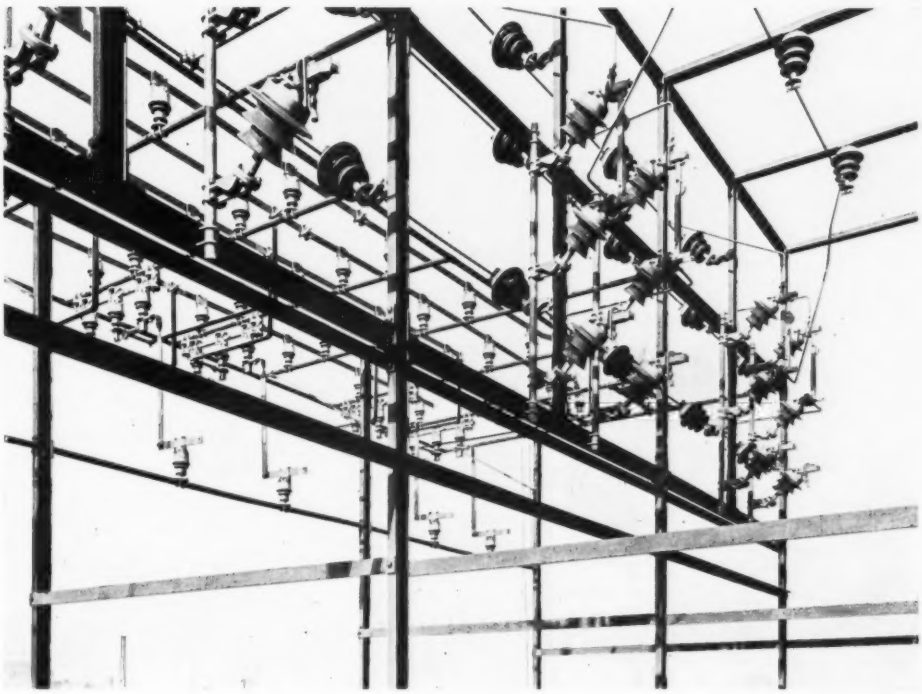


FIG. 1. VIEW SHOWING THE 33,000-VOLT THROW-OVER VERTICAL ISOLATING SWITCHES.

In the issue of this Journal for October, 1925, brief reference was made in the article on "Electricity Supply Developments at Preston" to the linking up by 33,000-volt cable of the supply systems of the Preston and Blackburn Corporations, so as to provide an economical means of interchanging power. For this purpose outdoor substations are being installed at each end of the interconnector to transform the generator pressure of 6,600 volts to 33,000 volts. The complete substation equipments, including transformers, induction regulators and switchgear, are of "English Electric" design and manufacture.

As outdoor switchgear is not as yet in general use in this country, some particulars of the apparatus being supplied may be of interest to our readers. Although in this instance the pressure is only 33,000 volts, the switchgear is typical of its class, and is illustrative of standard designs that are available up to 110,000 volts, and can readily be extended for any commercial voltage.

The general layout of the two substations is almost identical, and is shown in Fig. 2, while Fig. 4 is a view of the Preston substation prior to the installation of the transformers. In each substation the switchgear is carried on a light

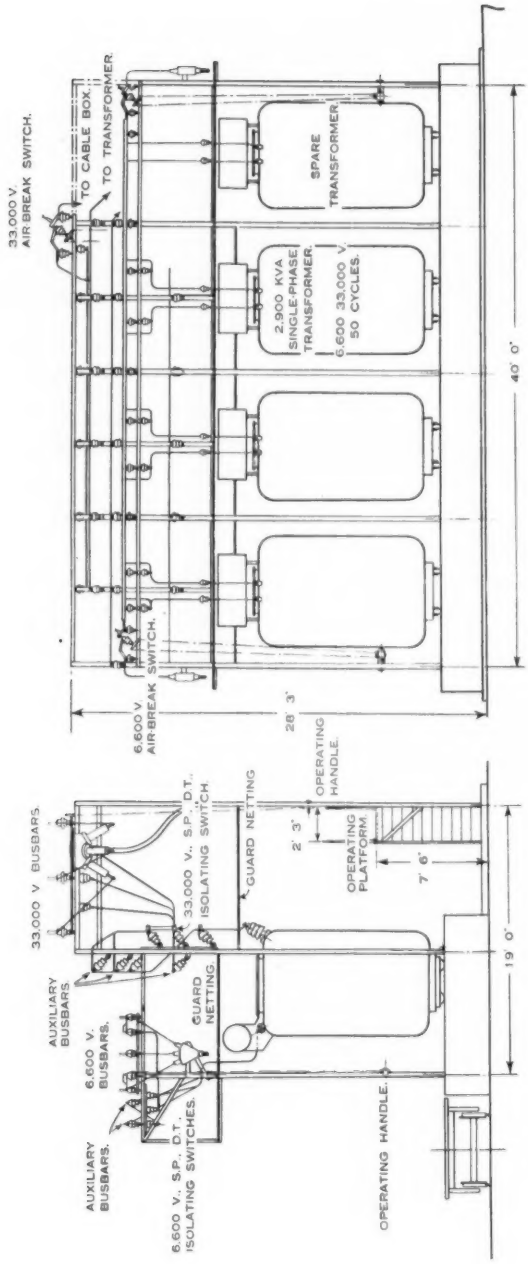


FIG. 2. GENERAL LAYOUT OF THE PRESTON AND BLACKBURN OUTDOOR SUBSTATIONS.

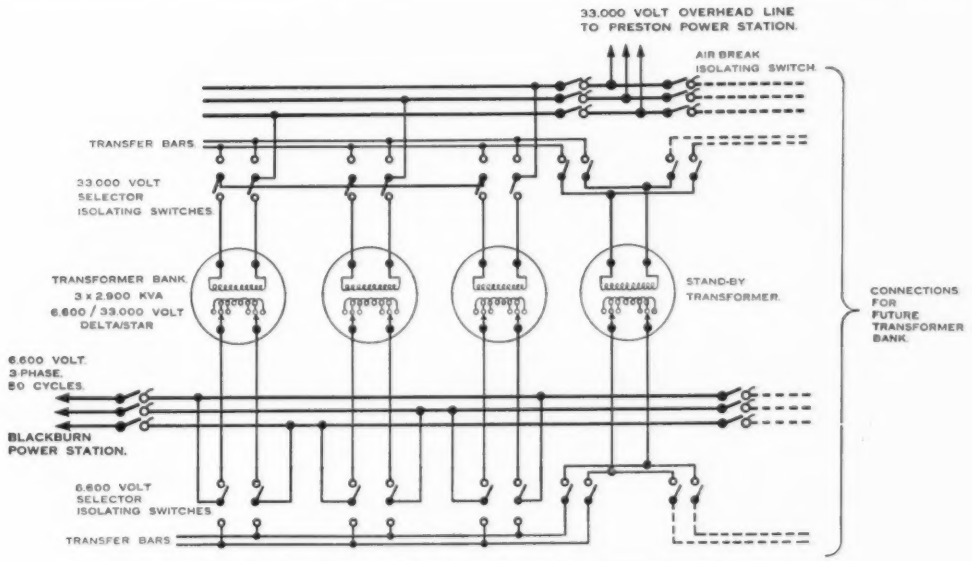

33,000 VOLT OVERHEAD LINE TO PRESTON POWER STATION.
AIR BREAK ISOLATING SWITCH.
TRANSFER BARS.
33,000 VOLT SELECTOR ISOLATING SWITCHES.
TRANSFORMER BANK. 3 x 2,900 KVA 6,600 / 33,000 VOLT DELTA/STAR
STAND-BY TRANSFORMER.
CONNECTIONS FOR FUTURE TRANSFORMER BANK.
6,600 VOLT. 3 PHASE. 50 CYCLES.
BLACKBURN POWER STATION.
6,600 VOLT SELECTOR ISOLATING SWITCHES.
TRANSFER BARS.

FIG. 3. DIAGRAM OF CONNECTIONS FOR BLACKBURN SUBSTATION.

steel structure, supported by a concrete plinth on which stand four single-phase, 2,900 KVA. transformers. The plinth is of such a height that the transformers can be wheeled directly on to a flat-topped truck running on rails at the side, thus avoiding the necessity for any lifting tackle.

The arrangement of selector switches is such that the fourth transformer can be readily connected in place of any unit in the three-phase bank, by means of throw-over isolating switches on both the H.T. and the L.T. sides. At the Blackburn end, of which the diagram is shown in Fig. 3, provision is further made for switching the spare transformer into any phase of a second bank which may be installed later, and by this means a single spare will be utilised as the standby unit for both banks.

Circuit-breakers of the oil-immersed type are not used in these substations, as full protection to the interconnector is provided by the oil circuit-breakers on the 6,600-volt side in the generating stations. As all load switching will be done on these oil breakers, it was considered adequate to install air-break switches in the 33,000-volt line. These switches are, however, provided with arcing horns, and are suitable for breaking small load currents such as transformer exciting currents.

The horn break switches are triple-pole units, as illustrated in Figs. 5 and 6, operated mechanically from a platform by means of a handle connected to the operating shaft by galvanised steel ropes. This operating shaft is of square steel of substantial section and carries a moving insulator forming part of the contact system. The moving contact and arcing horn are attached to the terminal insulator by flexible cable which is carried over links and guards to ensure the flexible connection being kept in position during operation and when open.

The fixed contacts are of the self-aligning, spring finger type, consisting of substantial copper fingers reinforced by galvanised steel springs. On the fixed contacts are mounted the stationary portions of the arcing horns, which are of inverted " U " shape, as shown. The horn on the moving contact is made up of

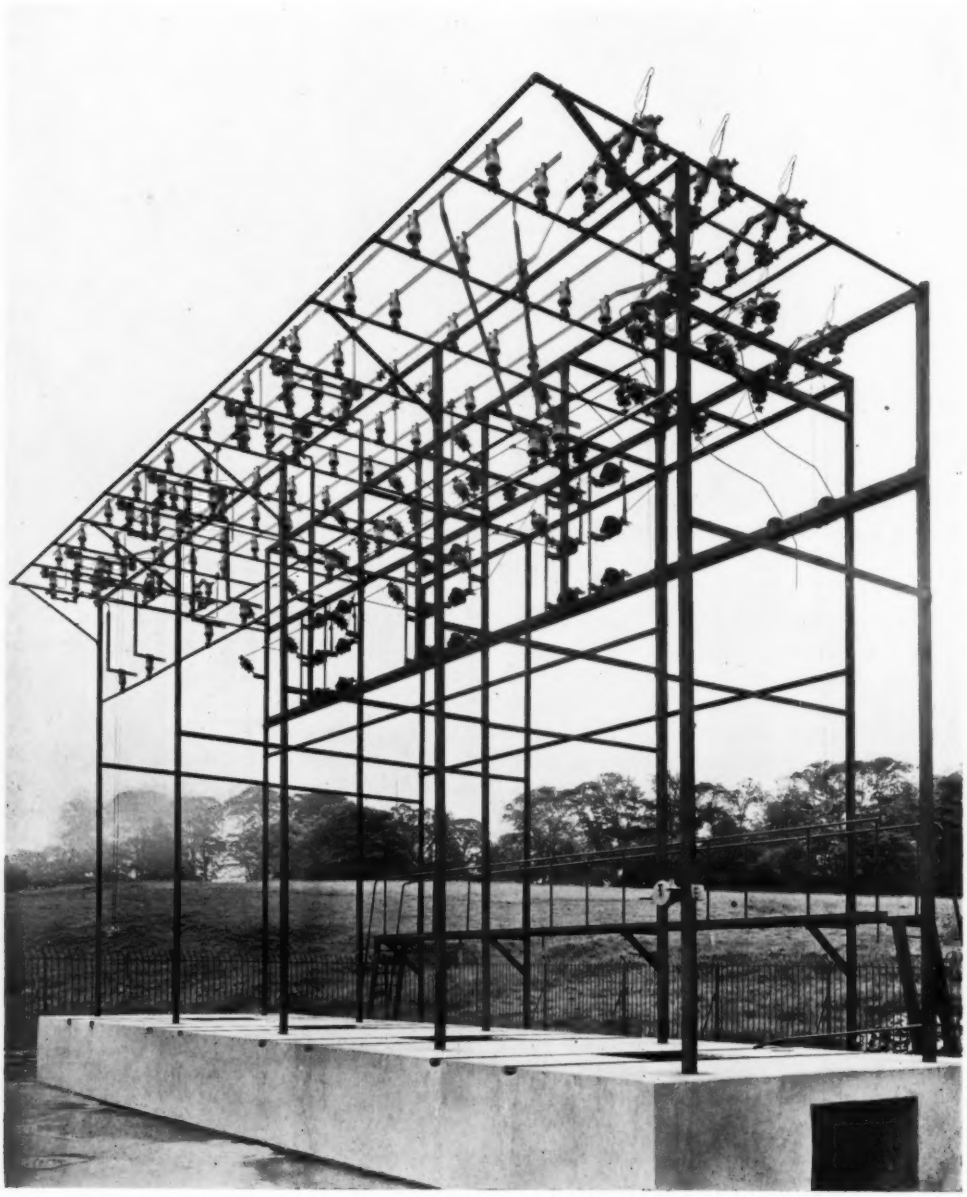


FIG. 4. GENERAL VIEW OF PRESTON OUTDOOR SUBSTATION BEFORE THE TRANSFORMERS WERE INSTALLED.

a single piece and moves between the legs of the " U " shaped fixed horn. The arcing horns, both of which are galvanised, are clamped to their contacts in a simple manner, so as to make replacement an easy matter. A view of a single-pole unit is shown in Fig. 5, and of a triple-pole group with its operating mechanism in Fig. 6.

All parts are readily accessible and interchangeable, and the method of securing the contacts by bolts in slots affords an easy means of adjustment. Furthermore, this type of contact by its scraping action ensures the drawing away of any sleet or snow, and thus renders the switches satisfactory for use under any weather conditions. All metal parts are galvanised, and all parts are strongly constructed to withstand any forces likely to be met with when operating, even though the contacts should be frozen together.

The isolating switches, both for 6,600 volts and 33,000 volts are single-pole units for pole operation. Examples of both the horizontal inverted mounting (6,600 volts), and the vertical mounting (33,000 volts), are shown in Figs. 7 and 8. Each switch is fitted with a safety catch which locks the blades in the closed position and prevents them from being opened by short-circuit currents, or by any means other than the operating pole. The insertion of the pole hook automatically releases the safety catch and when the switch has reached the " off " position the blades are held by spring clips which prevent the switch falling into the lower " closed " position.

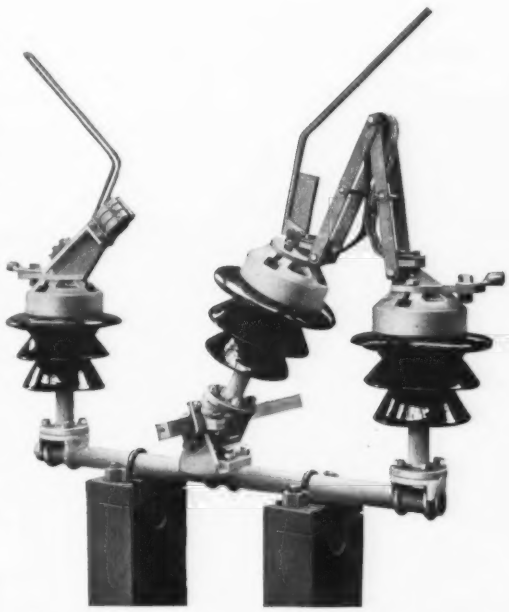


FIG. 5. 33,000-VOLT HORN BREAK SWITCH. OPEN.

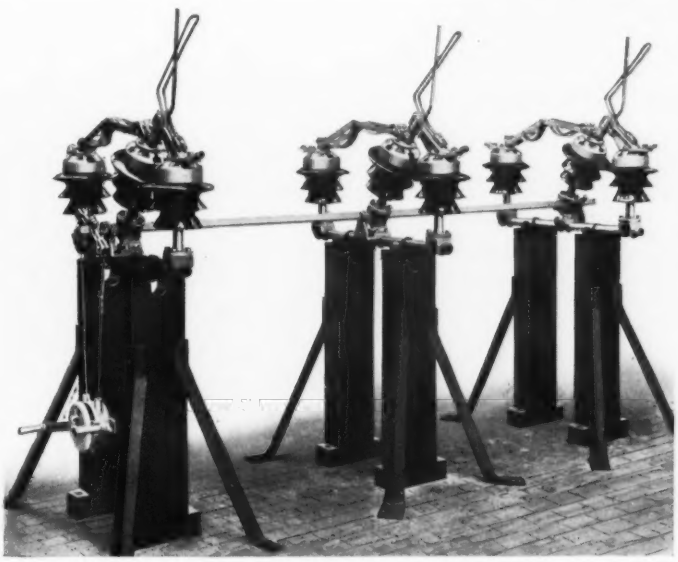


FIG. 6. 33,000-VOLT TRIPLE-POLE HORN BREAK SWITCH AND OPERATING MECHANISM. CLOSED.

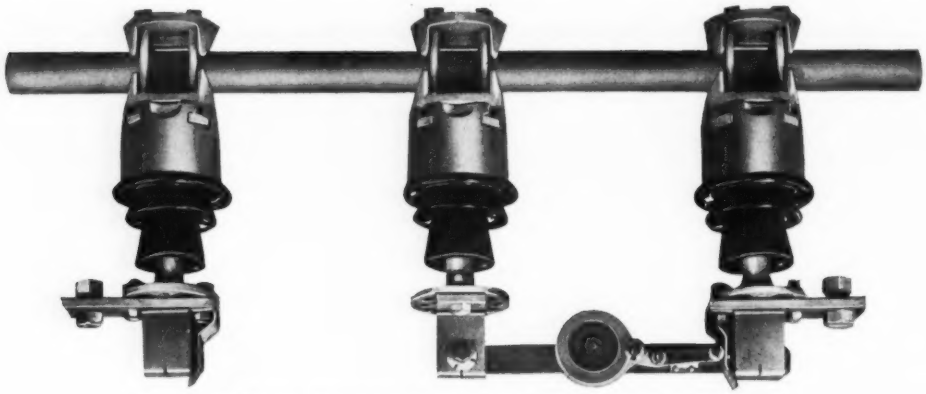


FIG. 7. 6,600-VOLT HORIZONTAL INVERTED THROW-OVER ISOLATING SWITCH.

The blades of the 6,600-volt isolators are of plain copper section, but those for 33,000 volts are stiffened, as shown in the illustration, to provide a rigid moving member and to ensure easy engagement of the contacts. The insulators employed are of the same type as for the horn break switches, and the contacts are similarly secured by bolts in slots, for easy adjustment. In the vertical isolators, the insulators are inclined at 45 degrees in order that the petticoats may serve their purpose effectively.

The busbars and connections are of copper strip and rod, and the insulators for supporting them are of the same pattern as, and interchangeable with, the insulators used on the isolating switches and the horn break switches. By making all the insulators for the same voltage interchangeable in this way the important advantage is gained that the number of spares which need be carried is reduced to a minimum. An earthed steel wire guard net fixed above the operating platform ensures the safety of the operator in the event of any mishap on the overhead gear.

The two types of air-break switch used in these substations form part of a standard line up to 110,000 volts, throughout which the designs are generally similar, except that above 66,000 volts two insulator units are employed in series.

FIG. 8. 33,000-VOLT VERTICAL ISOLATING SWITCH.

These switches may be considered as auxiliary to the complete line of " English Electric " oil circuit-breakers which has been standardised for the same range of pressures; these will form the subject of a later article.

Induction Voltage Regulators for Power Transmission.

Modern developments in the transmission of electric power by alternating current have created the need for apparatus capable of compensating for variations in line drop due to load and power factor, by suitable control of the voltage, and of performing this duty without involving any interruption of the supply.

Induction Regulators are rapidly gaining favour as a means of accomplishing this voltage control, on account of the following advantages :—

1. A perfectly smooth voltage variation is obtained.
2. Remote control or automatic operation can be easily applied.
3. No switches are required in the main supply circuit.
4. The construction is both simple and robust.

The English Electric Company, Limited, has developed designs of Induction Regulators which incorporate the results of the most modern research, and aim at a high standard of reliability with the least possible supervision. The Regulators are usually oil-immersed and either self-cooled or water-cooled, and the Company undertakes the manufacture of a variety of types up to any size required.

The maximum line pressure for which these Regulators are normally built is 11,000 volts. Above this pressure it is usually preferable to connect the regulator to the line by means of transformers, and by employing the " English Electric " Double-range principle (patent applied for) the increase in cost due to the inclusion of transformers is relatively small. This double-range principle, which is described fully on page 226, is also used for small regulators up to 11,000 volts where the direct winding of the primary for small input at high voltage would mean an unduly expensive and unreliable winding.

The general construction of an Induction Regulator closely resembles that of an Induction Motor, but the rotor is held stationary in a position which can be adjusted by suitable mechanism operated by hand or power. The primary or exciting windings are connected across the supply, and the secondary windings are in series with the circuit to be regulated.

FIG. 1. A TYPICAL WATER-COOLED INDUCTION REGULATOR.

Fundamentally, it is immaterial which winding is on the stator and which on the rotor, but in " English Electric " Induction Regulators the secondary winding is usually placed on the stator. This arrangement has the great advantage that the secondary windings and leads, which carry the heavier current, are rigidly fixed, and the movable windings and leads are confined to the primary circuit in which the current is relatively small.

Induction Regulators above 100 KVA., are wound in a 4-pole arrangement and require a mechanical movement of 90° to give full voltage variation in the normal type, and 180° for the Double-range type.

In the three-phase regulator the primary winding generates a rotating field as in the case of an induction motor, therefore the magnitude of the voltage induced in the secondary winding is unaffected by altering the position of the rotor. Movement of the rotor does, however, vary the phase relation of the induced voltage to the primary voltage, and hence the vector sum of the supply voltage and regulator secondary voltage also varies, and thereby the desired regulation is effected.

This is illustrated in Fig. 2, where AO represents the line voltage applied, OB the secondary voltage of the regulator, and AB the resultant regulated feeder voltage. In the extreme rotor positions corresponding to "*a*" and "*e*" the secondary voltage is respectively in conjunction with and opposition to the line voltage, and the resultant voltage AB then has its maximum and minimum values. For intermediate positions of the rotor the secondary voltage is out of phase with the line voltage, as shown in "*b*," "*c*" and "*d*," and consequently the resultant voltage has a phase displacement relative to the supply. On a simple feeder this is of no consequence, but on a ring main system, or where

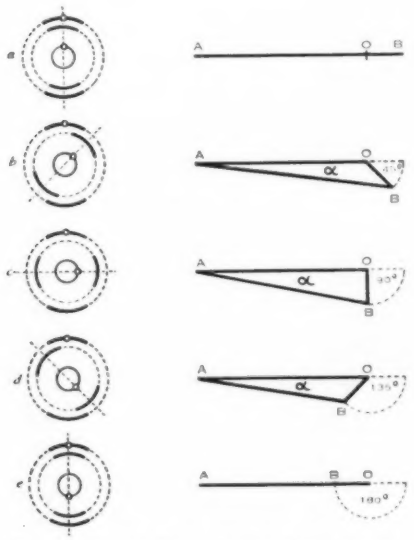


FIG. 2. PHASE VARIATION OF THREE-PHASE REGULATOR.

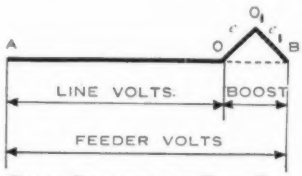


FIG. 3. PHASE RELATIONS IN TWIN THREE-PHASE REGULATOR.

the L.V. sides of transformers on two feeders are interconnected, this phase displacement may cause heavy wattless currents to circulate. To avoid this defect it is necessary to adopt either a Twin Three-phase Regulator, or a bank of three Single-phase Regulators. The Twin Regulator consists of duplicate three-phase regulators, simultaneously operated, each of half the required KVA., and with their secondary windings connected in series in such a manner that the phase shift of one is neutralised by the phase shift of the other. This is shown diagrammatically in Fig. 3, where AO is again the line voltage and AB the regulated voltage. OO_1 and O_1B are the secondary voltages of the two halves of the twin regulator. AO and AB are now in phase for all positions of the regulator.

The alternative apparatus for avoiding phase displacement, namely, a bank of three single-phase regulators, is more costly and less efficient than a three-phase regulator and, therefore, should be adopted only on a badly unbalanced system.

In single-phase regulators the secondary voltage is proportional to the alternating flux which threads the winding, and is, therefore, reduced from maximum to zero, as the rotor is turned from full boost position to neutral. If

the movement is continued, the direction of the flux relative to the secondary winding changes and the phase of the secondary voltage is reversed. A complete angular movement of the rotor through one pole pitch will, therefore, give full positive and negative range of regulation without any phase shift.

When the rotor is in the neutral position, the secondary and primary windings are not mutually inductive and the secondary would act as a choke tending to saturate the cores. To avoid this, an auxiliary short-circuited winding is provided on the primary and arranged electrically at right angles to the main primary winding. This additional winding, if properly proportioned, does not increase the losses in the regulator.

The stator core is built of thin laminations of very high quality, non-aging Silicon Steel, and one side of each lamination is coated with an insulating material that does not deteriorate with heating; additional insulation is interleaved at frequent intervals. The core is assembled in a rigid cast-iron frame of skeleton form and is held against rotation by means of keys. The design of the frame is shown in Figs. 4 and 6, and the arrangement of the members is such as to direct the flow of cooling oil to the various parts of the regulator in a measure proportionate to the heat production in them.

FIG. 4. STATOR OF THREE-PHASE REGULATOR.

Substantial tooth supports are fitted at the ends of the core to hold the teeth rigid and minimise vibration.

The rotor core is built with the same high grade material as is used for the stator core, and the laminations are keyed to a shaft of particularly generous design in order to ensure a very high degree of rigidity. Suitable ducts are provided in the rotor core for oil circulation.

Both the stator and the rotor windings are designed for operation on line voltage, where transformers are not interposed, and are insulated to withstand the severe shocks met with on high-voltage feeders.

The secondary, or series, winding is almost always on the stationary portion and is of the basket type in open slots; the portions outside the slots are supported to withstand severe short-circuit stresses by means of substantial rings in a similar manner to that adopted on large turbo-alternators. The arrangement of these windings is shown in Fig. 4 which illustrates the stator of an 870 KVA. Regulator ready for assembly.

FIG. 5. ROTOR OF THREE-PHASE REGULATOR.

The rotor winding, of which an example is shown in Fig. 5, is of the hairpin type with welded joints. Bakelite spacing pieces are inserted between the overhanging ends to form a solid ring, and the bent-back portions are substantially braced to support rings centred on the shaft.

The slot portion of the insulation in both members consists of specially treated paper, machine wrapped and hot pressed, to form solid moulded tubes. No material which will dissolve in, or discolour the hot oil is used for insulation or impregnation, and the materials chosen are not liable to deteriorate by the action of the oil.

Special attention may be drawn to the adoption of open type slots for the secondary windings and semi-closed slots for the primary winding; this combination allows a mathematically correct adjustment of slot openings so that the magnetic permeance remains uniform for all positions of the rotor, and thereby smooths the voltage regulating curve and practically eliminates tooth cogging and vibration.

Another interesting feature illustrated in Fig. 6 is the provision of an additional bearing close to the upper end of the windings. This adds very greatly to the rigidity of the shaft and has proved efficacious in reducing vibration and securing silent operation.

As a result of these important points of design an "English Electric" Induction Regulator performs with little, if any, more vibration than a transformer of the same size, and is practically as silent; further, as the insulation is relieved from unnecessary vibration and the resulting mechanical stress, any deterioration due to this cause is largely eliminated.

The connections are brought out from the windings through suitable cleats to terminals mounted on porcelain bushings in the cast-iron cover. For the leads from the primary winding on the rotor, heavily insulated flexible cable is used. To allow for the angular movement of the rotor each of the three cables forms a loose helix round the shaft and is supported in a suitably grooved sleeve of special construction. As shown in Figs. 6 and 7, this sleeve is designed so that the cables slide on smooth Bakelite surfaces under oil without any possibility of damage by chafing.

FIG. 6. A LARGE THREE-PHASE REGULATOR.

Those of our readers who are familiar with the design of "English Electric" Transformers, as described recently in these pages, will recognise in the following description many of the novel features which this Company has introduced into their tank construction.

In all cases the Tank is of boiler plate with welded seams and is provided at the top with a strong rim of steel to which the cover is bolted. Massive lifting lugs are riveted to the tank side, and in order to prevent

oil leakage along the rivet holes a thin plate of steel is welded inside the tank so as to enclose all the rivet heads ; the design of the tank and lugs is such as to permit the complete regulator to be lifted filled with oil. The tank is supported on a structural steel base in which plain or flanged rollers can be fitted if required, and is equipped with a drain valve, oil gauge, and a thermometer pocket.

Self-cooled regulators, examples of which are shown in Figs. 9 and 12, have circular tanks provided with external cooling tubes, welded into the tank side. This design gives maximum cooling efficiency and great mechanical strength, combined with a remarkably pleasing appearance.

FIG. 7. SLEEVE FOR ROTOR CONNECTIONS.

FIG. 8. WATER-COOLED THREE-PHASE REGULATOR.

Water-cooled regulators have plain circular tanks and the oil is cooled by means of a water cooling coil of solid drawn copper tube, mounted on the underside of the tank cover. A typical regulator of this kind is illustrated in Figs. 1 and 8.

The cover is of cast-iron ; the entire regulator is suspended from the underside, while on the top surface is mounted the complete operating gear. This arrangement renders it possible to lift the regulator out of the tank without disturbing any of the connections or mechanism.

Although Induction Regulators are sometimes required for direct operation by hand, as shown in Fig. 12, the more usual arrangement is to provide motor-driven operating gear and the necessary accessory apparatus for either remote control from a switchboard or for fully automatic operation.

The motor-driven mechanism for adjusting the position of the rotor consists of double-reduction worm and quadrant gearing fitted with ball thrust bearings on each shaft. The gear reduction is such as to give a suitable time

FIG. 9. A SELF-COOLED THREE PHASE INDUCTION REGULATOR FOR ± 10% REGULATION ON 8700 KVA.

for complete travel of the quadrant according to the size of the regulator, and the gearing is designed to give the best efficiency consistent with retaining the self-locking properties of worm reduction. The worms, wormshafts, and quadrants are proportioned to withstand the heavy twisting stress which occurs on short-circuit.

By careful selection of the gear ratios and by using a slow-speed motor, less power is taken from the line for operation, and where direct-current is available, a series motor may be used and switched directly on to the line without protective resistances. For remote control a small controller is supplied for switchboard mounting, with spring return to the "off" position. To prevent the motor from operating the regulator beyond the allowable limits two quick-make, quick-break, self-resetting limit switches are fitted, and in addition safety stops are cast on the cover at each end of the full travel of the quadrant.

As it is important that the motor should stop immediately the supply to it is switched off, the motor shaft is fitted with a brake drum on which works a spring loaded brake with self-adjusting Ferrodo-lined shoes. In the smaller sizes the brake is permanently adjusted to ensure quick stopping, and the motor is made large enough

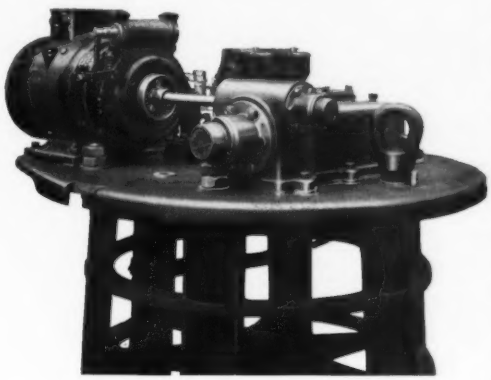


FIG. 10. OPERATING MOTOR, BRAKE AND REDUCTION GEARING.

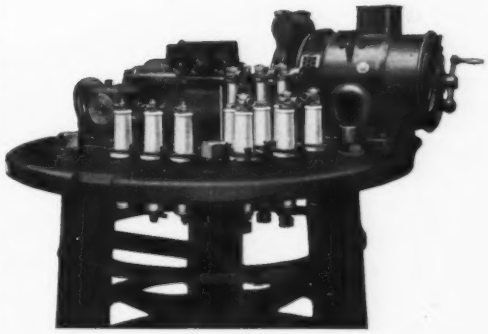


FIG. 11. TERMINALS AND MOTOR-OPERATING GEAR.

to overcome the brake friction. For sizes above about 200 KVA., the brake is released magnetically when the motor is switched on, but comes into operation instantly the motor circuit is opened.

For emergency use a handwheel or crank is usually provided. When a magnetically-released brake is fitted, a foot lever is added for releasing the brake pressure when it is desired to use the handwheel.

When induction regulators are used as Feeder Boosters, and particularly where the feeder has to supply a mixed load, it is frequently necessary to maintain by some automatic device a constant voltage at the remote end of the feeder, irrespective of the load. For this purpose "English Electric" Induction Regulators can be fitted with a sensitive type of relay which controls the operating motor through a pair of interlocked double-pole reversing contactors. As the voltage rises or falls this relay causes one or other of the contactors to close, thus allowing the motor to adjust the position of the regulator rotor and restore the line voltage to its predetermined normal value. If the load is mainly lighting, or otherwise in the neighbourhood of unity power factor, reverse compounded series turns on the solenoid of the relay alter the basis voltage according to the load. If, on the other hand, the load is of a mixed nature, and the

power factor differs appreciably from unity, it is necessary to include a line drop compensator, which incorporates both resistance and reactance, and reproduces the line drop characteristics of the feeder.

The relay is specially designed to make a firm contact as soon as critical voltage is reached, and is fitted with no-volt contacts so that the regulator is returned to minimum volts position if the voltage fails. To prevent unnecessarily frequent operation of the regulator due to merely momentary fluctuations of voltage, adjustable time-delay relays can be supplied which energise the contactors only after a suitable time interval.

The " English Electric " Double-Range Induction Regulator has already been mentioned. It consists of an Induction Regulator with 1 : 1 ratio between rotor and stator windings. Both windings are in series with the line, and voltage is applied to one member from a transformer. Each winding is therefore half the KVA. of the total regulation required. This arrangement is particularly advantageous for comparatively small outputs at high voltage. Let us take as an example, an 11,000-volt line having a full load of 1,200 KVA., for which an Induction Regulator is required to provide voltage regulation amounting to $\pm$ 10%. The full-load current per phase would be 63 amperes. In a simple three-phase regulator the primary winding would have to be wound for a current of about 7·5 amperes and would require about 60 conductors per slot. It is extremely difficult to construct a winding of this description so that it will satisfactorily withstand the mechanical and electrical stresses to which it will be subjected in service. By adopting in this case a Double-range Regulator in which both windings carry the full line current, the number of conductors per slot is relatively small, and a thoroughly robust apparatus is obtained, while the inclusion of a transformer is compensated for by the reduced size of the regulator, so that neither cost nor efficiency is appreciably affected.

Fig. 14 shows the arrangement adopted and Fig. 13 is the voltage diagram. A movement of the regulator rotor through one pole pitch gives a range from full boost to zero boost, while a further travel of one pole pitch gives a range from zero to maximum negative boost. The change over of connections is accomplished automatically by the travel of the rotor and entails no special operation on the part of the attendant. Moreover this change is made at zero voltage across the regulator, when there is only the exciting current of the transformer to break.

For pressures above 11,000 volts, the arrangement shown in Fig. 14 is modified by interposing a series transformer between the regulator and the line, in which case the regulator is in an independent circuit and the windings can be designed for any suitable voltage irrespective of the line voltage. This

FIG. 12. 11,000-VOLT THREE-PHASE REGULATOR WITH HAND OPERATION.

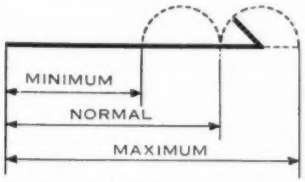


FIG. 13. VOLTAGE VARIATION WITH DOUBLE-RANGE REGULATOR.

arrangement is also used for split-phase conductors requiring voltage regulation, in which case a common regulating transformer and common series transformer are used for both conductor circuits.

The two principal uses of the Induction Voltage Regulator as here described are as Feeder Boosters and in Interconnector circuits.

All transmission of electrical power is accompanied by losses which manifest themselves as a drop of pressure along the transmission system, and the magnitude of the losses and pressure drop varies with the load and power factor. Apart from Rules and Regulations as to the permissible departure from the declared voltage, this variation of pressure is very undesirable, at any rate beyond certain limits depending upon the class of load served. Where the load consists mainly of motors a certain fluctuation of pressure is not liable to criticism, although induction motors show an increased slip with reduced voltage and the overload capacity is reduced as the voltage squared.

On the other hand the increasing application of electrical energy for heating purposes and for various electro-chemical processes calls for a closer regulation of pressure, while lighting demands the greatest possible uniformity of pressure. By introducing an Induction Regulator at one or more points on a system, it is possible to compensate for the pressure drop due to low power factor and C^2R losses, and in many cases investigation of the financial factors shows that the desired regulation can be obtained more cheaply in this way than by increasing the section of copper used for the line, or conversely that a larger load can be carried economically by an existing line without exceeding the desirable limits of pressure variation; the capital charges of the Induction Regulator, together with its running charges and those for the increased line losses, will often be found to be less than the capital charges due to an increased copper section in the line.

Induction Regulators for feeder voltage control may be placed either at the supply end or at the consumer's end of the line. If at the consumer's end then the exciting current of the regulator has to be transmitted, and supervision is usually easier at the supply end. The best position is usually at a distributing substation, where the drop on the line from the generating station to the substation and also the drop on the distributing feeder can both be compensated.

Where two power stations are coupled together through an interconnector, an induction regulator may be used to control the distribution of energy between the two. The action of the regulator in this instance is quite different, as the circuit on which it is operating connects in parallel two sets of alternators. The determination of the size and operating conditions of Induction Regulators on Interconnector systems is a complicated matter, and requires complete knowledge of the characteristic of the interconnector line and the stations coupled. The English Electric Company are in a position to make thorough technical

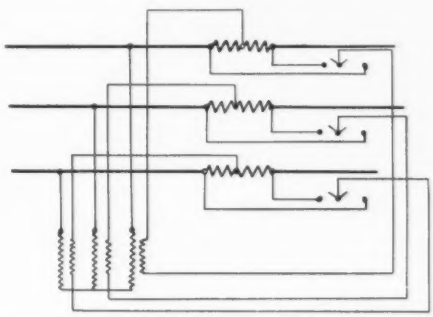


FIG 14. CONNECTIONS OF SIMPLE DOUBLE-RANGE REGULATOR

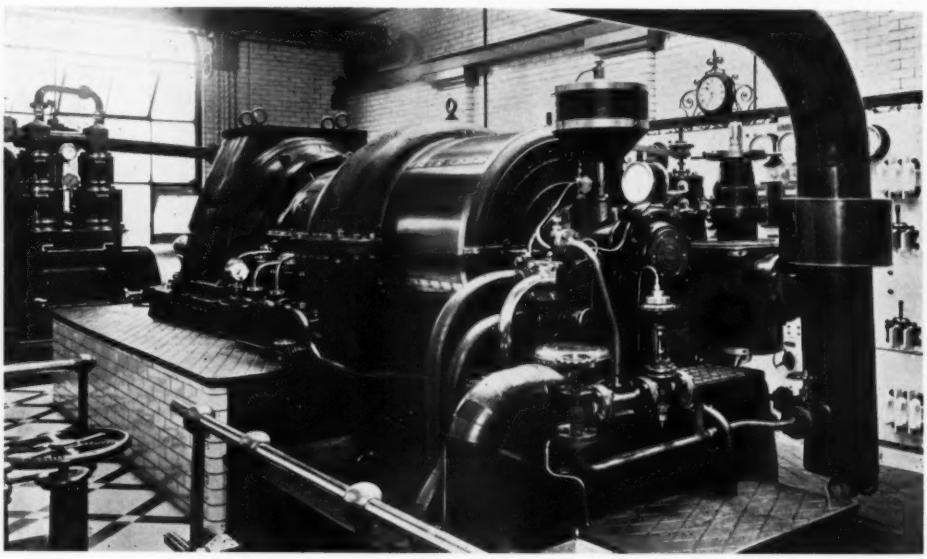
investigations and advise as to the most satisfactory solution for problems of this kind.

Induction Regulators form the ideal method of voltage control on Rotary Converters where the range required is greater than can be obtained economically by reactance control, where unity power factor is required over a range of voltage, or where voltage regulation is required in conjunction with inverted running. For any of these purposes the " English Electric" Class XR. Low-Voltage, Air-Cooled, Regulators are ideal; they are described in a special publication No. 586.

Induction Regulators are also a valuable method of voltage control for high-voltage testing sets, for cable testing, and for oil testing sets; they are also serviceable for furnace work where very large currents at low voltage are used, control being effected by a regulator in the primary circuit of the transformer.

Small induction regulators, often called phase shifters, are also used for instrument calibration.

In addition to the large number of Induction Regulators which have been supplied or are in course of construction by The English Electric Company, they manufacture also Booster Transformers of all types. This alternative class of apparatus possesses advantages for feeder regulation in certain cases, and it is hoped to describe them in a future issue of this Journal.



1,250 *KW. Alternator Gear-driven by* 6,000 *R.P.M. Steam Turbine in the Power House of a Lancashire Textile Factory. In the Background is a Willans Central-valve Engine. The Turbine also was built at Willans Works, Rugby.*

"English Electric" Motors in Service.

[Although Electric Power is fully established as the best means of driving all classes of industrial machinery, many new installations present fresh points of interest from both the technical and the commercial aspects. It is hoped that this series of articles will be of value to our readers by indicating the trend of modern practice in the application of electric driving to the several industries or public services to which reference is made.—EDITOR.]

I. Dock Pumping at Southampton.

The complete electrification of the whole of the Southern Railway's pumping plant at their Southampton Docks is no mean tribute to the commercial and technical advantages of electric power, for the docking of the largest liners is a costly process that admits neither of delay nor of wasteful engineering methods. The Docks generating station formerly supplied the lighting, and, since 1911, an increasing proportion of the handling machinery ; but in 1923 a comprehensive scheme was decided upon for doing away with all stationary steam plant. At the present day the maximum demand is 3,500 KW.

The whole of the electricity supply is now obtained from the Corporation System, and that this arrangement has been made is not only interesting as being indicative of the modern tendency to suppress private plants, but is instructive in regard to certain provisions which make this policy profitable alike to the consumer and to the supplier. One of these provisions concerns the maintenance of a reasonable load factor, and the avoidance of a heavy maximum demand charge, to which end the docking programme is planned to avoid simultaneous dry docking operations at the larger docks. The second feature to which particular attention may be directed as an example of modern practice in electric driving, is the undertaking entered into by the Railway Company to install, in the case of motors of over 200 H.P., machines which would give a leading power factor, in consideration of which the Corporation agreed to base their charges on a kilowatt-hour instead of a kilo-volt-ampere hour basis.

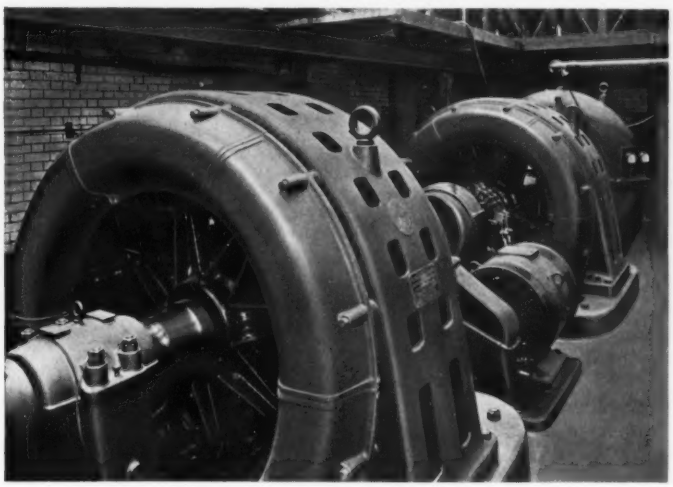


FIG. 1. TWO 950 H.P., 250 R.P.M. ASYNCHRONOUS-SYNCHRONOUS L.A.S. MOTORS. ·9 LEADING POWER FACTOR.

A very complete description of the Docks power supply and the great variety of electrical applications was given by Mr. H. Wauchope, the Electrical Engineer of the Docks and Marine Department of the Southern Railway, in a paper which he read last August at the Southampton meeting of the British Association, and we are indebted to him for much of the information which the Railway has kindly permitted us to publish.

The main contractors for the dry docking pumps were

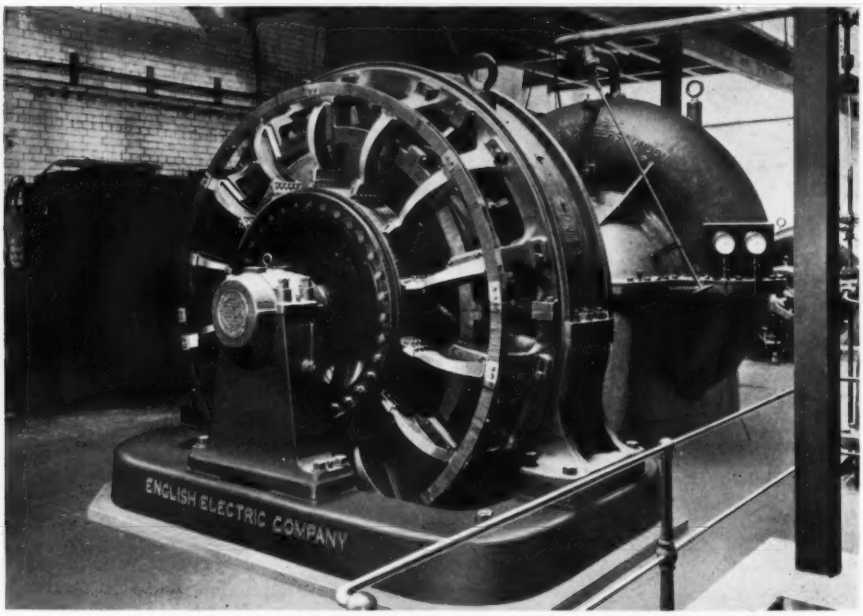


FIG. 2. 1200-H.P., 210/245-R.P.M. DIRECT-CURRENT C.S. MOTOR.

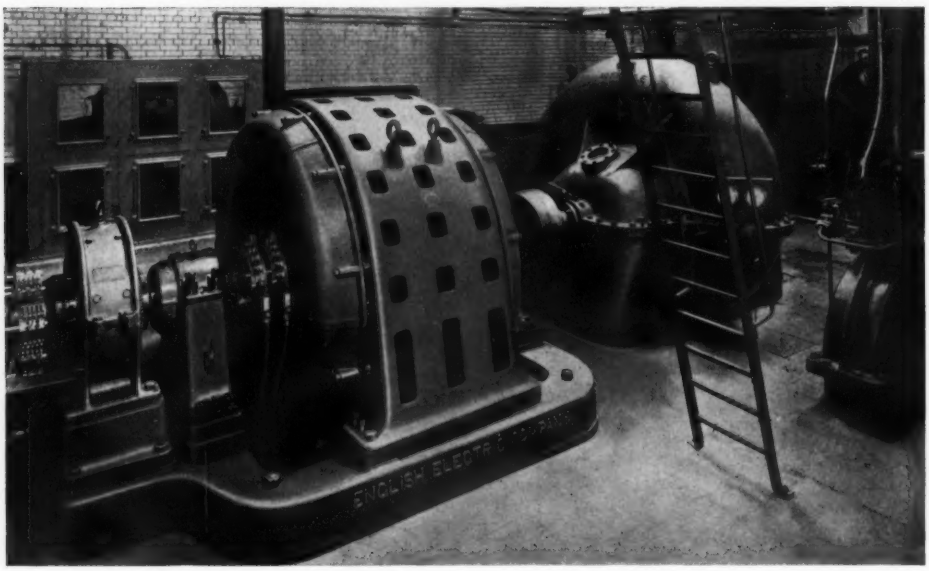


FIG. 3. 1200-H.P., 231-R.P.M. ASYNCHRONOUS-SYNCHRONOUS L.A.S. MOTOR, 0·9 LEADING POWER FACTOR.

Gwynnes Engineering Co., Ltd., to whom some 6,000 H.P. of " English Electric " motors were supplied in connection with the electrification scheme and whom we have to thank for particulars relating to the individual pumps.

The largest pumping units are those installed in No. 6 Pumping House, which is adjacent to the Trafalgar Dock and contains the main substation for the distribution of electrical energy throughout the Docks. The de-watering plant for the Trafalgar Dock is installed on the main pump floor 25′ 6″ below the ground level and consists of two centrifugal single-impeller pumps having 48″ branches; each pump is capable of discharging an average of 450 tons of sea water per minute against a head varying from 0 to 37 feet. One of the pumps is driven by an A.C. motor and the other by a variable-speed D.C. motor which provides for the slow pumping operations which are sometimes necessary; each motor has a full-load output of 1,200 H.P. These two motors, as well as all other docking pumps, are provided with push-button contactor control gear. The A.C. machine, illustrated in Fig. 3, is of the standard " English Electric " Asynchronous-Synchronous type designed for a full-load power factor up to 0·9 leading and runs at 231 R.P.M. on a 6,600 volt, 3-phase, 50-cycle supply.

The starting of this type of motor is arranged so that by the pushing of the starting button the machine starts up as an ordinary asynchronous or induction motor, and when full speed has been attained an automatic change-over switch connects the exciter to the rotor windings; then the motor pulls into synchronism automatically and continues to run as a synchronous machine. The power factor is regulated, as required, by varying the exciting current supplied to the rotor by the separate D.C. exciter.

The 1,200 H.P. D.C. motor, shown in Fig. 2, is a 14-pole, shunt-wound, 500-volt machine of the latest " English Electric " design, with a speed range of 210 to 245 R.P.M.

In the same house there is a third 48″ pump which is used for impounding purposes, and is capable of delivering 200 tons of water per minute in order to raise the level of the water in the dock above the tide level, as required, to a maximum of 16 feet. This unit is driven by an asynchronous-synchronous motor having a full-load output of 350 H.P. at a speed of 214 R.P.M., and with a power factor, as before, up to 0·9 leading. There is also in this house a small sump pump driven by a standard A.G. squirrel-cage induction motor; this unit is capable of lifting 300 gallons per minute against a total head of 35 feet.

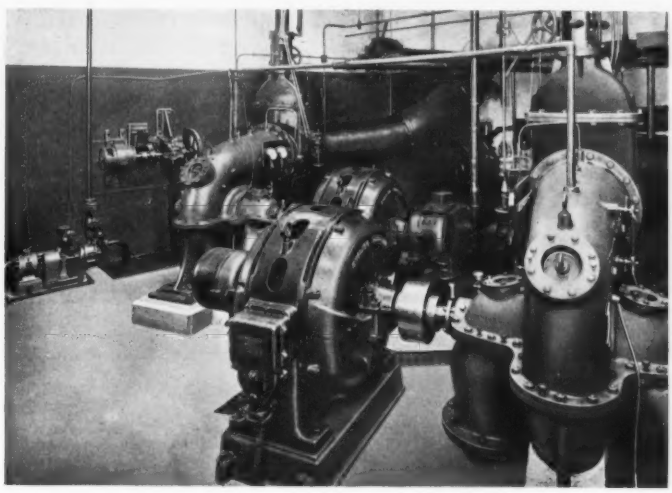


FIG. 4. 175 H.P., 416 R.P.M., L.S. INDUCTION MOTORS.

In No. 5 Pump House, 24 feet below ground level, are installed two 48″ pumps, like those in No. 6 Pump House, but the duty of 350 tons per minute each against a head of 0 to 35 feet necessitated motors of 950 H.P. only. Both these machines are of

the asynchronous-synchronous type, running at 250 R.P.M., 0·9 leading power factor, and the equipment and operation is similar in all respects to that at No. 6 House, except that owing to the limited space available, the exciters had to be staggered and are driven from the rotor shafts by means of chain drives, with the interposition of centrifugal clutches to avoid sudden shocks. A general view of these two motors is shown in Fig. 1. There are, in addition, a drainage pump and house pump, each driven by a squirrel-cage induction motor.

The No. 4 Pumping Station contains two 24″ pumps, which can be used for emptying either No. 4 or No. 3 dry dock by the operation of electrically driven sluice gates; these pumps are driven by slipring Induction motors of 175 H.P. running at 416 R.P.M. on a 415 volt supply. Fig. 4 is a general view of the equipment, and shows also the auxiliary pumps for house service and for priming the main pumps. No. 3 Pump House for Docks 1, 2 and 3 contains plant which is precisely similar to that just described.

II. New Purification Works of the West Kent Sewerage Board.

These important new Works which were inaugurated recently at Long Reach, Dartford, are the latest example of the progressive policy adopted by the Board since its constitution in 1875.

The various pumps, elevators, screens, etc., are driven by standard "English Electric" squirrel-cage induction motors, the electric supply being furnished by the Dartford Urban District Council in the form of 3-phase, 50-cycle alternating current transformed down to 400 volts.

After passing through a Venturi Meter and a Rough Screen Chamber, the sewage passes into the Screening House, of which a view is shown in Fig. 1. This is equipped with two mechanical screens from which the rags, paper, etc., are removed by heavy brushes driven through clutches and gearing by squirrel-cage K motors of 6 H.P. running at 935 R.P.M. The heavy material not taken out by the screens is removed by an elevator driven by a similar motor of 2 H.P., running at 1390 R.P.M.

From the Screening House the material flows through distribution pits into a four-foot channel and thence into the Detritus Tanks, which are in duplicate, and have a total capacity of 375,000 gallons. For removing the detritus from these tanks the travelling dredger, illustrated in Fig. 4, is employed. This is driven by a totally enclosed A.G. motor, rated at 15 H.P., 720 R.P.M.

By way of further channels the sewage flows into the Precipitation Tanks, of which there are 24 with a total capacity of 6½ million gallons. The floors are of inverted pyramidal form and have 5 inch outlet pipes at the centre which are connected to the pump houses. In each pump house there is a Stereophagus pump capable of lifting 465 gallons of sludge per minute against a head of 43 feet, and driven by a vertical spindle, 12 H.P., 1425 R.P.M., A.G. motor, similar to the one illustrated in Fig. 5.

The sludge from the Precipitation Tanks is discharged into specially prepared drying beds that cover

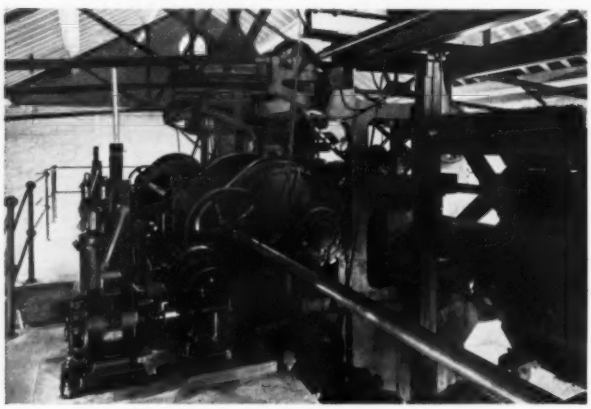


FIG. 1. K MOTORS DRIVING SCREEN BRUSHES.

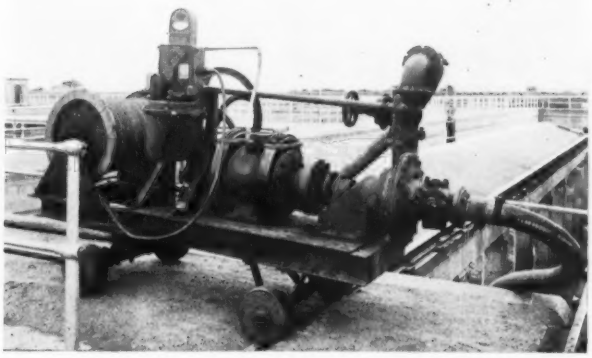


FIG. 2.
TRANSPORTABLE PUMP DRIVEN BY 7½ H.P., 960 R.P.M. TOTALLY-ENCLOSED A.G. MOTOR.

FIG. 3.
TEMPORARY OUTDOOR PUMP DRIVEN BY TOTALLY-ENCLOSED A.G. MOTOR.

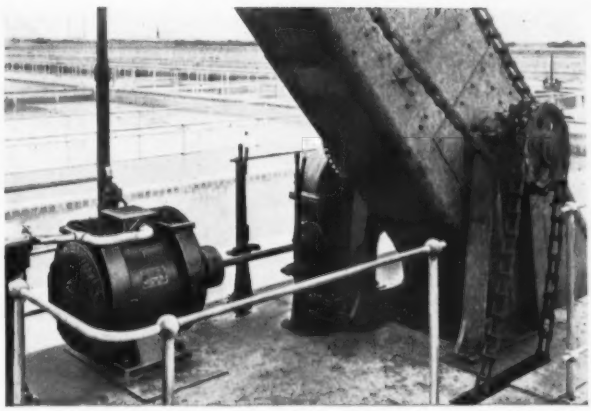


FIG. 4.
TRAVELLING DREDGER DRIVEN BY 15 H.P., 720 R.P.M. TOTALLY-ENCLOSED A.G. MOTOR.

57,000 square yards and deal with 2,000 cubic yards of wet sludge weekly. The bottom of the beds is of porous construction, and the drainage water is led into an underground storage tank from which it is lifted by a Stereophagus pump of 450 gallons per minute capacity against a head of 32 feet. The driving motor is an A.G. machine rated at 8 H.P., 940 R.P.M., and is controlled by an automatic float starter. The effluent from the Precipitation Tanks flows into the River Thames or, when the tidal level is too high, into large Storage Tanks of $4\frac{1}{2}$ million gallons normal capacity. The humus deposited in these tanks is removed by a pumping set similar to that used for the drainage water, the motor again being of 8 H.P. In this pump house, shewn in Fig. 5, is a six-stage turbine pump driven by a 10 H.P., 1435 R.P.M., K motor for the purpose of delivering a portion of the effluent to all parts of the works for cleaning purposes.

Fig. 2 shows a transportable 4 inch Stereophagus pump which can be transferred from point to point as required ; it is driven by a totally enclosed squirrel-cage A.G. motor, rated at $7\frac{1}{2}$ H.P., at 960 R.P.M. A further example of the use of totally enclosed motors for outdoor service is the temporary drive illustrated in Fig. 3.

In the Administration Building there is a workshop equipped with a lathe, drilling machine, grinder, etc., driven from countershafts by a 5 H.P., 960 R.P.M., K motor, while a saw bench is separately driven by a second machine of the same size.

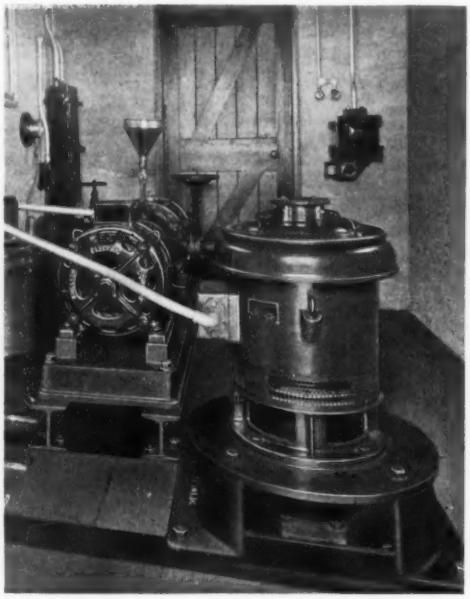
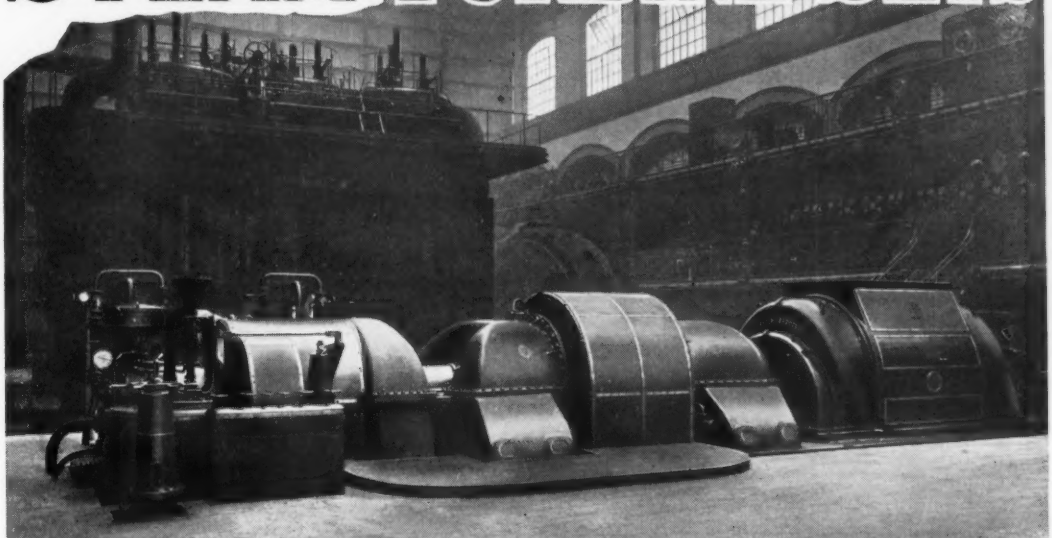


FIG. 5. 8 H.P. VERTICAL A.G. MOTOR DRIVING HUMUS PUMP AND 10 H.P. K MOTOR DRIVING TURBINE SERVICE PUMP.

TWO-CYLINDER STEAM TURBINE SETS



16,000 K W. 3,000 R.P.M.

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